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STUDIES OF THE FATE OF CERTAIN RADIONUCLIDES IN ESTUARINE AND OTHER AQUATIC ENVIRONMENTS JULIUS J. SABO ET AL PUBLIC HEALTH SERVICE WASHINGTON D C DIV OF RADIOLOGICAL HEALTH PHS PUB 999 R 3 85P MAY 63.

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Radiological Health

# STUDIES OF THE FATE OF CERTAIN RADIONUCLIDES IN ESTUARINE AND OTHER AQUATIC ENVIRONMENTS

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# STUDIES OF THE FATE OF CERTAIN RADIONUCLIDES IN ESTUARINE AND OTHER AQUATIC ENVIRONMENTS

*Edited By*
*Julius J. Sabo*
*Paul H. Bedrosian*

Proceedings of a Symposium held in Savannah, Ga., to study various aspects of radiological surveys of aquatic environments.

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Radiological Health
Washington 25, D. C.

# FOREWORD

The operation of nuclear power facilities, whether on or under the sea or in land-based plants, has not been possible without the generation and discharge of wastes containing radionuclides. In order to determine the extent, magnitude, and possible effects of such discharges on living organisms, the efforts of scientists representing many disciplines are called upon.

The reports presented in this Symposium illustrate the high degree of cooperation that comes into play in the design, performance, and interpretation of investigations dealing with the radiological aspects of environmental health. In this series of studies, disciplines represented by hydraulic engineers, geologists, sanitary engineers, biologists, ecologists, chemists, and statisticians were engaged. It is noteworthy that Government, both Federal and State, and Industry were represented at the Symposium as sponsors, organizers, participants, and attendees. This reflects the broad range of interests that exist concerning radiological surveillance of aquatic environments.

In his report, Mr. Harris discusses the hydraulics of the Savannah Estuary, detailing various characteristics of river and tidal currents, salinity distribution, and sedimentation in estuarine waters. The physical and chemical features of a water system determine the design and interpretation of a sampling program. Biological and ecological studies become more meaningful when implemented by such information.

Messrs. Sabo, Baptist, and Rueter present a broad picture of several aspects of surveillance methodology, including: the establishment of baseline radiation levels to which future findings can be referred; the derivation of data which can be applied to the determination of radionuclides in marine waters and to the development of control measures; the determination of appropriate indicator organisms that can be used in measuring the concentration of radionuclides in a marine environment; and the development of information that would help in ascertaining how radioactive wastes might affect the fisheries industry. Their report describes the design of equipment for collecting samples, the performance of radiological studies on sediment, water, and biological material, and the processing of data so that comparisons can be made with similar data from other areas.

Dr. Rice describes various experimental findings that need to be considered in measuring the uptake of radioelements by organisms. He shows the importance of designing such laboratory experiments to simulate natural conditions. Without this kind of research, field surveillance programs might have to depend largely on trial and error, and laboratory results would be difficult to correlate either with other laboratory findings or with results obtained in field studies.

Dr. Friend, in consequence of his field studies, has delineated the fate of radionuclides as influenced by the chemical, hydrologic, and geologic dynamics of certain river systems. His investigations suggest that more useful information can be gained when specific nuclides, rather than gross activity, are studied. An interesting method of concentrating radionuclides with the aid of organic materials suspended in streams under controlled conditions is described.

The Symposium points up the importance of coordinated effort among scientific groups; demonstrates the complexity of estuarine and other aqueous surveillance; and introduces improvements in certain sampling techniques--especially for silt collection. It adds to the store of knowledge that is needed for the safe use of nuclear power, and demonstrates that better surveillance methods and keener understanding of radioactivity in man's environment are products of progressive research both in the field and in the laboratory.

James G. Terrill, Jr., Deputy Chief
Division of Radiological Health
Public Health Service

## ACKNOWLEDGMENTS

This symposium was sponsored and arranged by the Division of Radiological Health, Public Health Service, because of the interest expressed by members of various Federal and State agencies. Gratitude is extended to all those who made this symposium possible and in particular to:

Robert Abel, Executive Secretary of the Coordinating Committee on Oceanography, Office of Naval Research, who did much to encourage this undertaking;

J. G. Terrill, Jr., Assistant Chief, Division of Radiological Health, Public Health Service, for his advice and support in the documentation of the proceedings of this symposium;

E. C. Anderson, Chief, Special Projects Branch, Division of Radiological Health, Public Health Service, for his keen interest not only in this symposium, but also in the general field of radiological monitoring;

Representatives of the Bureau of Commercial Fisheries, Department of the Interior, who did much to support this symposium, and the U.S. Coast Guard, Treasury Department, for their support and assistance in providing ships and crew.

Credit is also due to Public Health Service Officers Fred G. Rueter, Assistant Sanitary Engineer, and Ronald Caton, Junior Assistant Sanitary Engineer, for their efforts in the actual planning and arrangement of the symposium.

J. J. Sabo
Project Officer
Division of Radiological Health
Public Health Service

P. H. Bedrosian
Project Officer Pro tempore
Division of Radiological Health
Public Health Service

## ABSTRACT

In a symposium on the fate of radionuclides in the Savannah River Estuary and in two river systems, procedures are described which can usefully be applied to investigations of other aquatic systems. The studies involve surveillance and monitoring techniques and the development of equipment and methods. A discussion of the hydraulics of the Savannah Estuary describes the characteristics of river and tidal currents and distribution of salinity and sedimentation; these form a basis for effective sampling and interpretation of radiological data and their application to aquatic and ecological studies. Field and laboratory studies on the accumulation of nuclides by organisms are described and interrelated. It is shown that more useful information can be developed when specific nuclides, rather than gross activity, are investigated. Improvements in sampling methods, especially in silt collection, are described in detail. These studies emphasize the multidisciplinary aspects of radiological surveys of aquatic environments.

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May 25, 1961 - Savannah, Georgia

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# WELCOME AND INTRODUCTORY REMARKS

by

Dr. Walter A. Chipman

Atomic Energy Officer, Bureau of Commercial Fisheries, Department of the Interior

This Symposium has been planned to acquaint you, as representatives of various Federal and State agencies and others interested in the Savannah River and Estuary, with the work now going forward and to solicit your comments and advice as to ways to conduct these studies to yield the best possible information on the radioecology of this estuary.

The Bureau of Commercial Fisheries welcomed the opportunity to work with the Public Health Service in carrying on an ecological and environmental radiological study in the lower Savannah River. The Bureau is very much interested in matters of the hydrology and biota of estuaries since estuaries play such an important part as a habitat of many commercial fish and shellfish. Also, some oceanic species are in estuaries at times and often during certain critical stages in their life histories. In addition, we are particularly interested in obtaining information as to the fate of radionuclides introduced into estuaries and the uptake and accumulation of these nuclides by the biota. It is our hope that the present studies of a natural habitat in the Savannah Estuary will supply information on the cycling of radionuclides, and hence of other nuclides in an estuarine environment. Information is desired of the availability of radionuclides for uptake by the biota both from the water and sediments, their accumulation by different organisms, and their passage through food chains leading to commercially important fish and shellfish. This study would then complement and verify the radiological results being obtained in the laboratory.

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# OPENING ADDRESS

by

E. C. Anderson

Chief, Special Projects Branch,* Division of Radiological Health, Public Health Service

I wish to welcome you gentlemen for the Division of Radiological Health, Public Health Service.

The Special Projects Branch formed the Savannah Estuary Environmental Radiological Survey (SEERS) Project in August 1960. At that time there was considerable interest in oceanic disposal of radioactive wastes, and the Public Health Service was asked what studies it was conducting in this field. The Service, after due consideration, decided that a study of the disposal of packaged, solid, radioactive wastes would not be productive since there was an inherent lag of 5 to 10 years between the dumping of the packages and the release of their radioactive materials to the water environment. The Service, therefore, undertook the study of a marine environment that has been receiving liquid radioactive wastes.

Before effective monitoring of radioactive wastes discharged to the marine environment can be accomplished, the fate of these wastes and their pathways into man's marine food supply must be determined. What effect these radioactive materials have on any of the organisms in the food web must also be determined, and at the same time, valuable data as to indicator organisms might be obtained. To realize these objectives, an aquatic marine environment containing small amounts of man-made radioactives wastes should be investigated. The Savannah River Estuary is ideally suited for this type of investigation because the Savannah River has been receiving liquid radioactive wastes discharged from the U. S. Atomic Energy Commission's Savannah River Plant located at Aiken, South Carolina.

The SEERS Project is not only a surveillance study, but also a study designed to develop monitoring techniques, equipment, and methods. These developmental aspects are concerned primarily with the radiological interests for which the project was originally conceived.

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*Subsequently renamed Technical Operations Branch.

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# HYDRAULICS OF THE SAVANNAH ESTUARY

by

J. W. Harris

Chief, River and Harbor Section, U. S. Army Engineer District, Savannah, Georgia

## Introduction

Savannah Harbor includes a portion of the lower Savannah River and a channel across the outer bar to deep water in the ocean. The vicinity map in figure 1 shows the geographic location of the harbor. The present authorized maintenance project provides for a channel 36' deep at mean low water and 500' wide from deep water in the ocean to the harbor entrance; thence 30' deep and generally 400' wide to the Georgia Ports Authority terminals; thence 30' deep and 200' wide to the upper limit near the Atlantic Coastal Highway bridge.

The Savannah Harbor Investigation and Model Study conducted by the U. S. Army Corps of Engineers was begun in 1949. The study has dealt primarily with shoaling in the navigation channels and with factors affecting the shoaling. Extensive measurements of the velocity, salinity, and sediment concentration for various tides and fresh water discharges were made and used for construction and verification of the hydraulic model of Savannah Harbor.

The following is a brief discussion of the data and findings based on prototype and model data which are pertinent to the shoaling and which are believed related to the concentration of radioactive deposits.

The principal sources of the shoaling material are the Savannah River sediments and sediments brought in by the tides. The bulk of the shoaling material consists of silts and clays finer than 230-mesh sieve. Sand-size particles, having been transported as bed load by the Savannah River and by the tidal currents, are found in small quantities in the extreme upper and lower ends of the harbor.

The suspended sediment load of the Savannah River was determined from a river survey which commenced in 1949. Figure 2 is a map of the Savannah River Basin which shows the locations of the sampling stations used in the survey. The primary sampling locations were Clark Hill Dam at river mile 237.5 and Clyo at river mile 65.

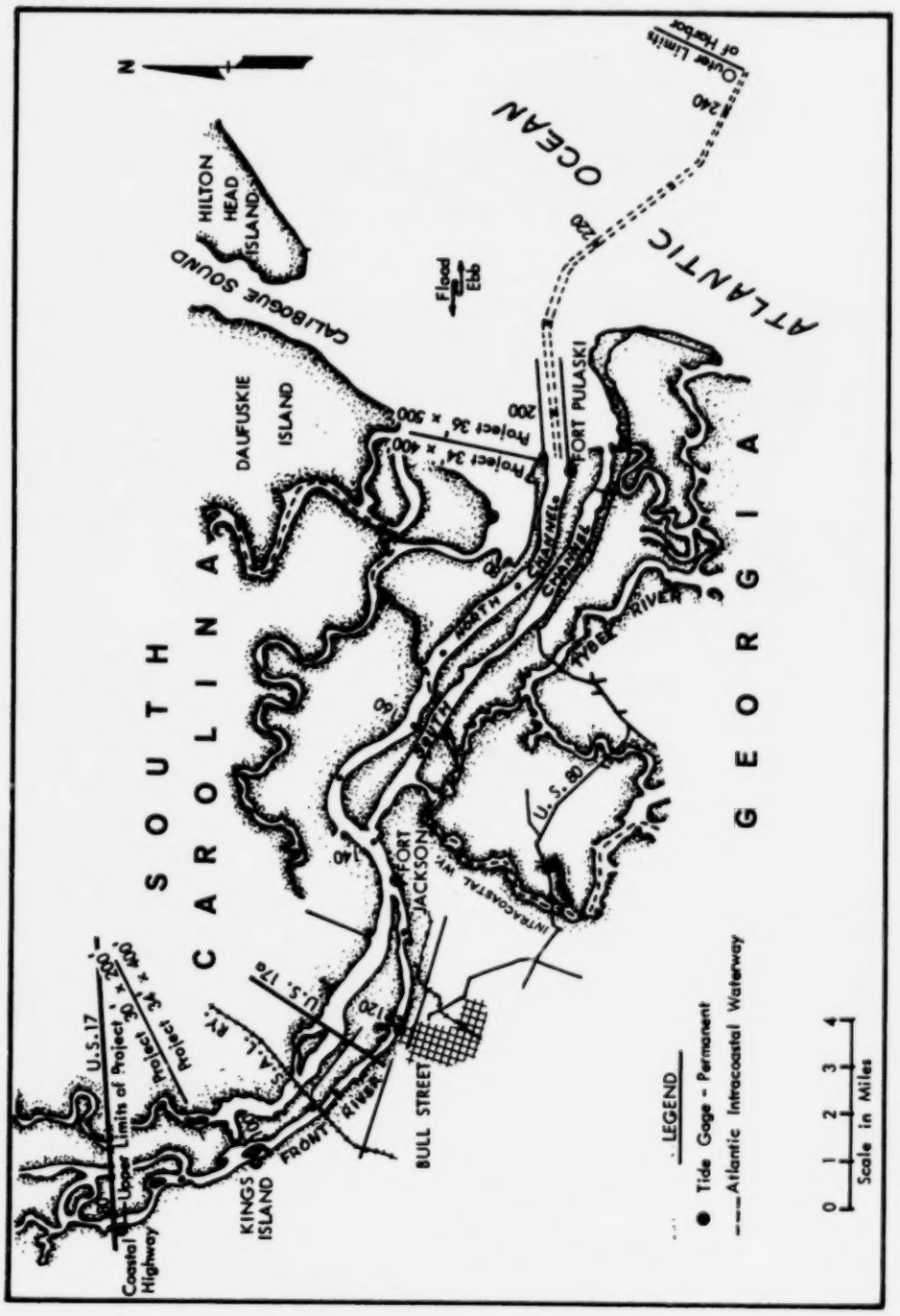


Figure 1.–Condition of Savannah Harbor, 1959

The construction of Clark Hill Dam was started in December 1946 and was completed in 1952. Sediment records indicate that the sediment load contributed to Savannah Harbor by the river was reduced by about 5 percent by the construction of Clark Hill Dam. This reduction has not been distinguishable from harbor dredging and shoaling estimates.

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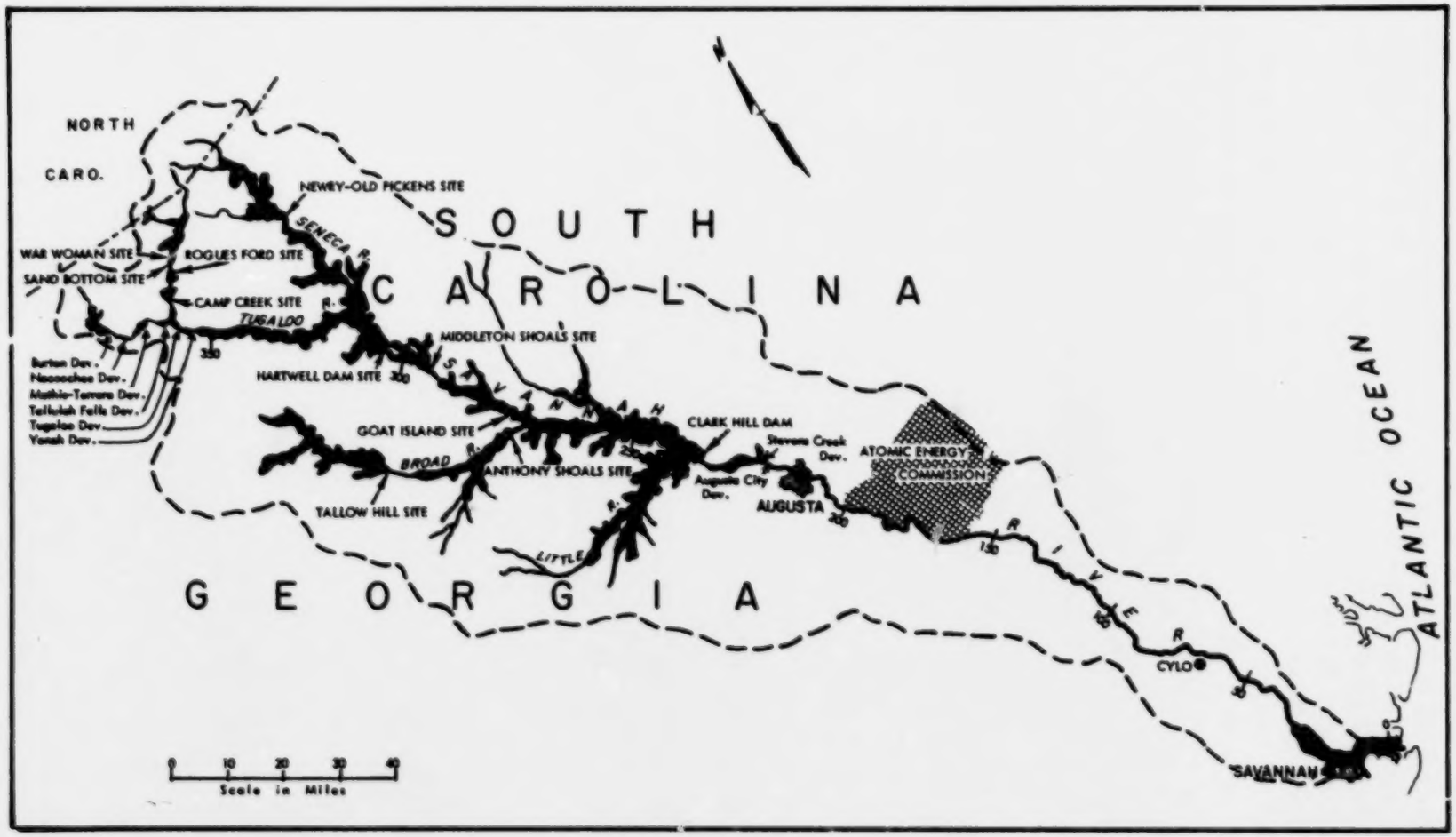



Figure 2.-Savannah River Basin

The annual sediment load attributed to the Savannah River is about 360,000 tons, of which 78 percent is suspended sediment and 22 percent is colloidal sediment. The suspended sediments are sustained in suspension by the velocity of the river and are deposited in the harbor when the velocities are reduced by tidal action. Particles transported in a state of colloidal suspension are deposited in the harbor after they have been flocculated by the sea water. This phenomenon and the action of the tidal currents are the primary factors in controlling the location of the shoaling.

## The Salt Water Wedge

In his paper, Mr. Ralph F. Rhodes[1] describes the salt water wedge as follows:

> At low water slack, all of the water in the tidal prism has been voided and there remains in the lower river only the water which fills the low water prism. In the upper part of the tidal section of the river, this water is all fresh. In the lower section, particularly near the mouth and if the volume of fresh water discharge is equal to an appreciable part of the total tidal prism, a part of the low water prism is salt water lying on the bottom and extending into the river above the mouth, somewhat in the form of a wedge. The plane of separation, however, between this wedge and the fresh water above is not well defined, and all data obtained indicated that it consists of a layer of water of varying thickness, in which the density increases from top to bottom. Available data also indicate that this plane becomes less sharply defined as the distance above the mouth increases.
>
> At points where fresh water forms part of the volume of tidal prism and saltwater the remainder, low water slack

[1] Head Engineer (retired in 1950), Department of the Army, Corps of Engineers, Savannah, Georgia

> occurs and flood flow begins first on the bottom before there is slack water on the surface. This early flood flow is composed of the heavy salt water in the wedge as it penetrates the river. If, during the preceding ebb flow, the salt-water wedge has retreated to a point considerably below the locality in question, all layers at the locality are fresh and the flood movement begins at all depths at about the same time. If the limit of retreat is only a short distance below the locality, the first flood movement is in the fresh water on the bottom, and is caused by the approach of the salt-water wedge from below. At points in the tidal section where the water in all layers has the same density, all fresh water or all salt, ebb flow begins at all depths at about the same time. Where the fresh water occupies the upper layers and salt water those below, ebb flow begins in the upper layers first (1).

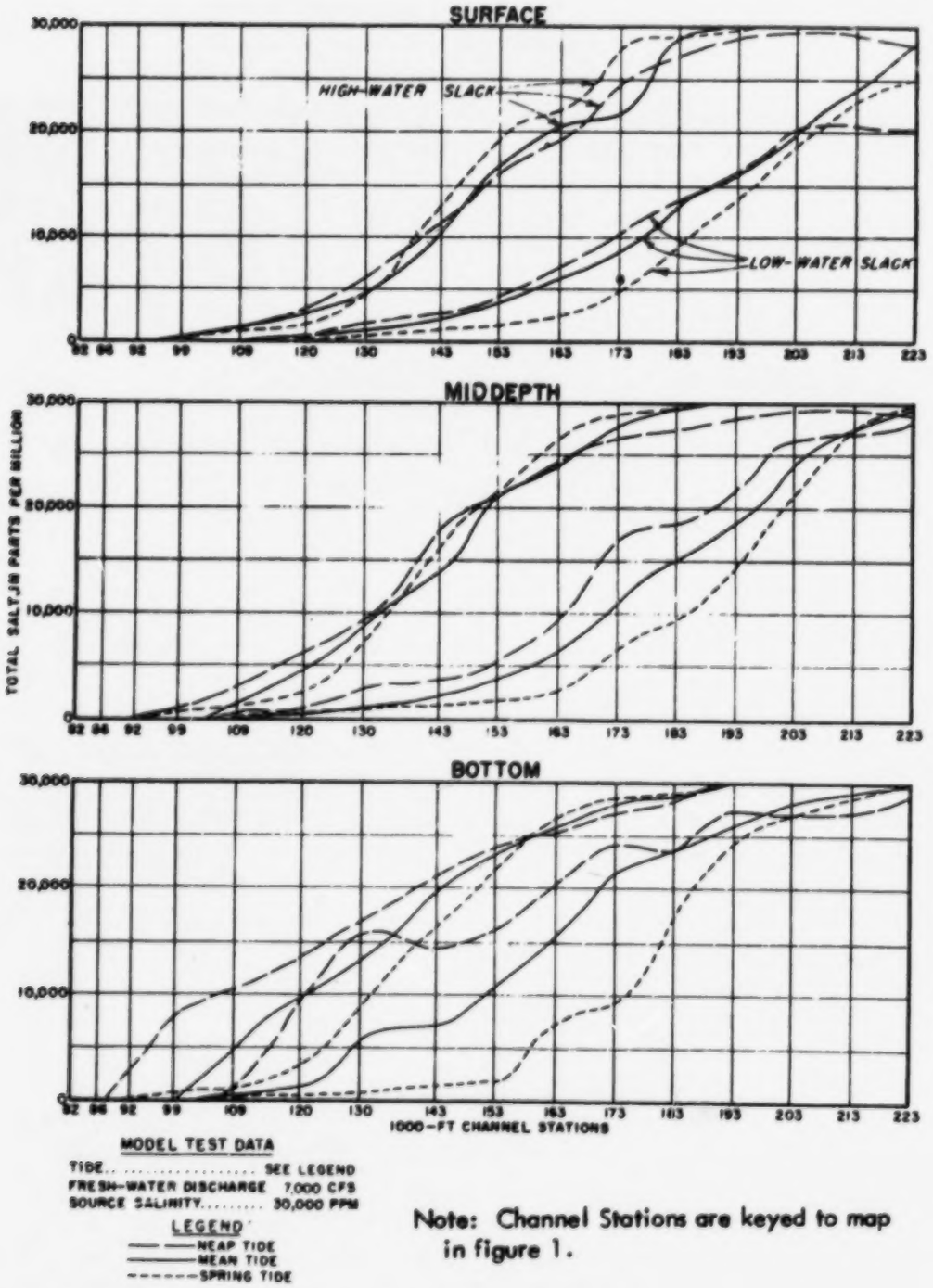
### The Effect of Spring and Neap Tides on the Salt Water Wedge

The observed salinities verify the principles discussed above and also show a marked variation in their concentrations depending on the fresh water discharge and the tidal range in which a particular observation was made. Figure 3 shows that the neap tides tend to extend the salt water intrusion upstream on the bottom and that spring tides, because of the greater quantity of salt water entering the harbor, caused increased salinities throughout the vertical in the lower reaches. Channel stations are keyed to the map in figure 1.

### The Effect of the Salt Water Wedge on the Location of Shoaling

The present shoaling regimen can be related to the location and movement of the salt-water wedge. Under normal conditions the salt-water wedge extends on the bottom to about Station 100 and retreats to about Station 140 (see figure 1). Figure 4 shows that about 88 percent of the shoaling in the inner harbor occurs within this area. This is evidence that the salt water wedge is a prime factor in controlling the deposit

of shoal material. High fresh water discharge can cause the location of the shoaling to shift downstream and can also cause the same effect on the salt water wedge.




Note: Channel Stations are keyed to map in figure 1.

Figure 3.-The Effect of Tides on the Salinity Profile

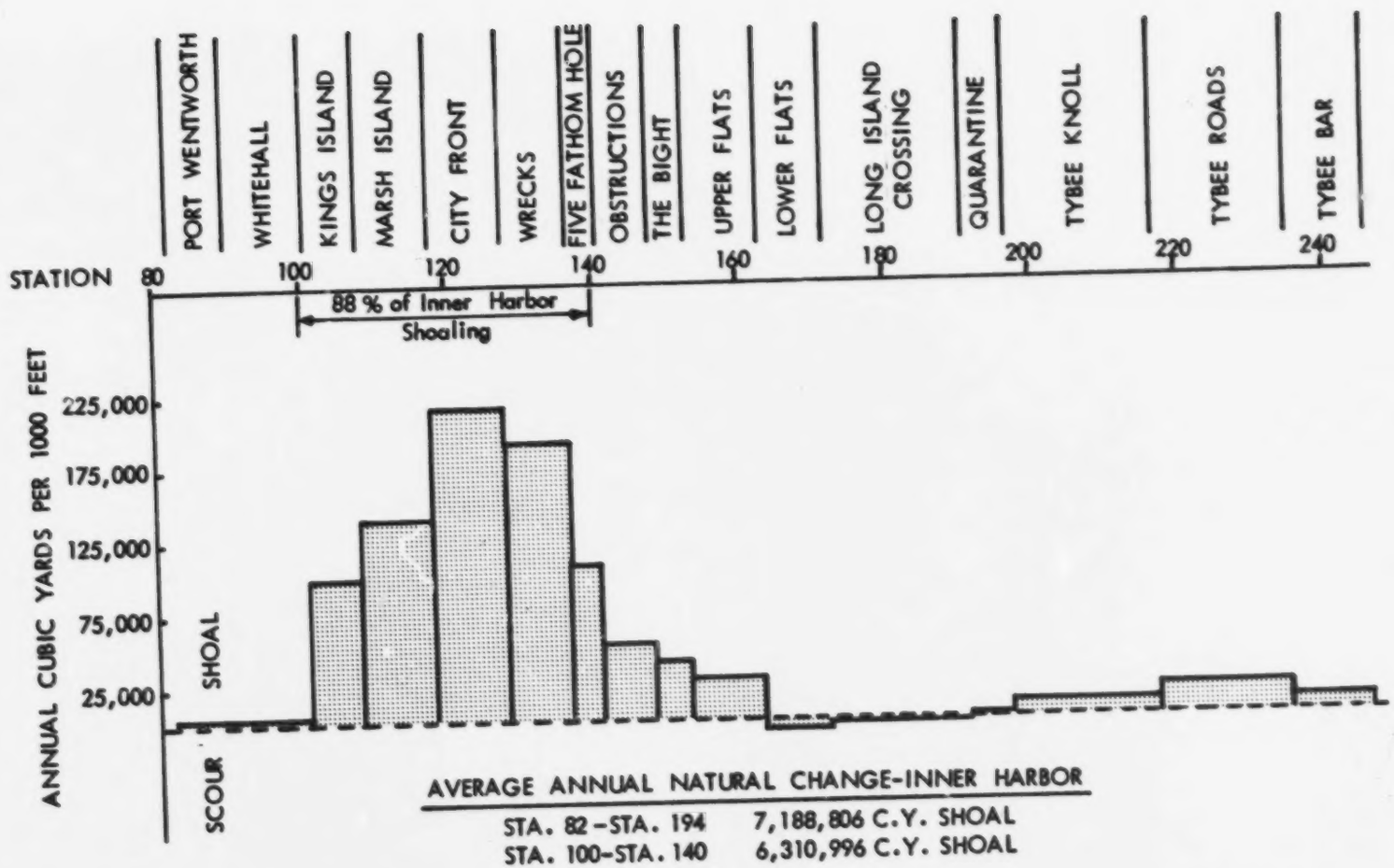



Figure 4.-The Effect of Natural Shoal and Scour on Savannah Harbor during the Period 1953-1957

### Predominance of Flow

As a result of his studies, Simmons (2) has developed an expression which combines the analyses of velocities, directions, and durations of currents into a single form called "predominance of flow." Plots of predominance of flow data for mean conditions existing in Savannah Harbor are shown in figure 5. The flow data are expressed in percentages of total flow in the direction of flood or ebb at a specified location and depth, and are an effective means of evaluating the effect of velocity and duration of flow on shoaling. Equilibrium of flow represented by the node point indicates conditions which are conducive to shoaling, and establishes a relationship with the salt water wedge.

### The Effect of Salinity on Flocculation of Sediments

The sediment load carried by the Savannah River into Savannah Harbor consists of: coarse-sand-size particles which are transported by bed load movement, suspended sediments which are deposited when flow velocities are reduced, and the colloidal clay and organic particles which are flocculated by the electrochemical action of the sea water on mixing with the river's fresh water. About 22 percent of the total sediment load is colloidal and will not settle out in the harbor until it has come in contact with the salt water. It was determined in the laboratory that about 5 parts per thousand of sea water salinity is normally sufficient to completely flocculate Savannah River water, and the flocculation usually takes place in from 3 to 12 hours. Prior to evacuating the harbor, all the fresh water brought in by the Savannah River will have mixed with the salt water to result in a net salinity which would still be greater than that required for flocculation and within the time required for complete flocculation. By considering the action of the salt-water wedge and the predominance of flow computations, it is concluded that practically all colloidal sediments carried by the Savannah River are precipitated in the harbor. One would also expect shoaling to be concentrated in the area where the mixing of the fresh and salt water occurs. This is found to be true.

In addition to causing the colloidal sediment load to be deposited in the harbor, the flocculation process may hasten the precipitation of suspended sediment particles brought in by the Savannah River or by some other source and may concentrate the deposition in the sections where the fresh and salt

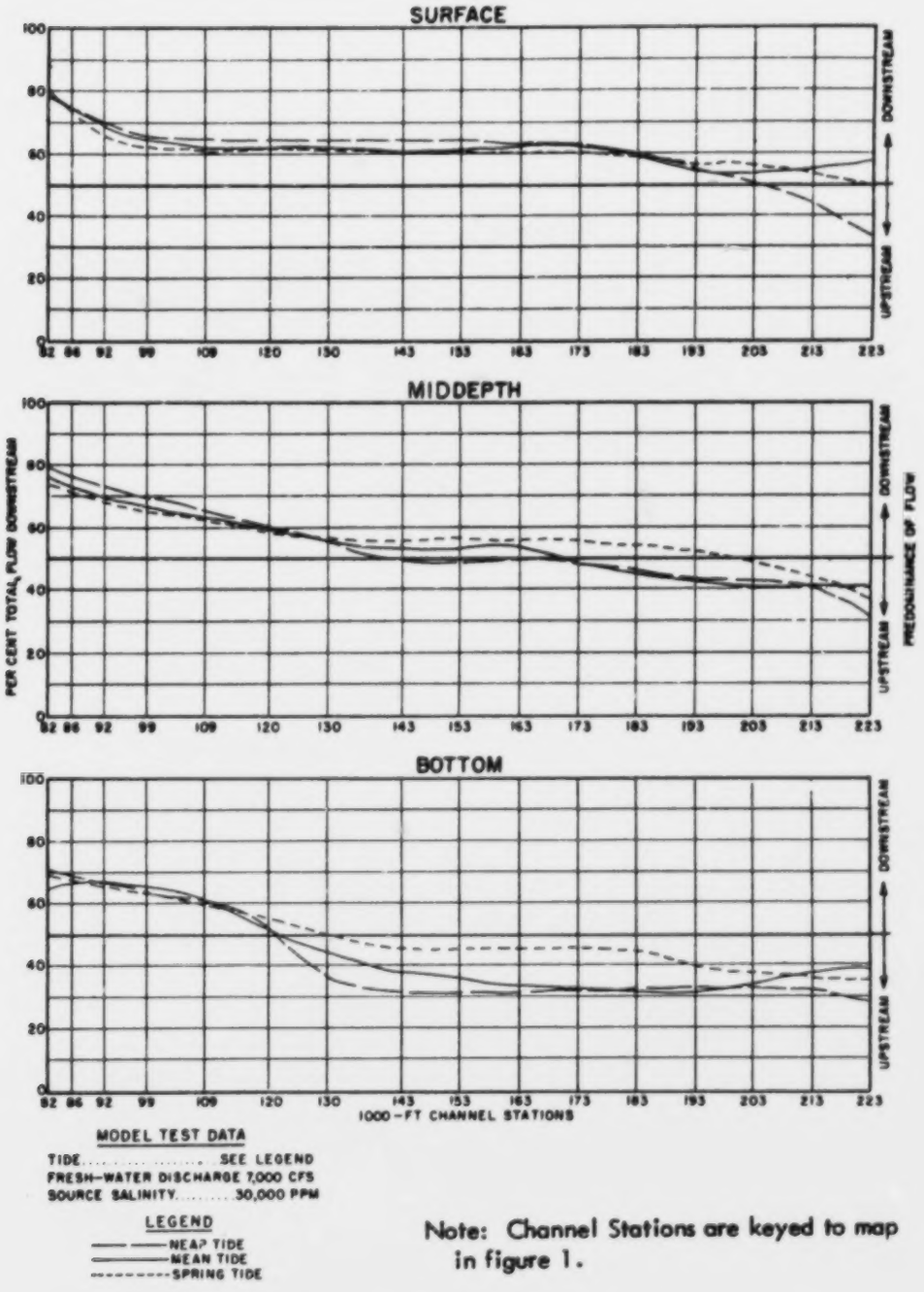



Figure 5.-The Effect of Tides on the Predominance of Flow

water mixing occurs. Therefore, radiological contamination of the estuary's sediments would probably be more pronounced in the areas of greatest shoaling than in other areas. The shoals are generally well mapped since their locations and quantities are controlled by the tides, the salt water intrusion, and by the fresh water discharge.

Harbor improvement plans are being tested by use of a Hydraulic Model located at the U. S. Waterways Experiment Station, Vicksburg, Mississippi. By such research activities, general hydraulic data for various tidal and fresh water flow conditions have been and will continue to be developed.

## References

(1) Rhodes, Ralph F.: The Hydraulics of a Tidal River as Illustrated by Savannah Harbor, Georgia, Corps of Engineers, U. S. Army, Savannah, Georgia (January 1949), p. 102.

(2) Shultz, E. A., and H. B. Simmons: "Fresh Water-Salt Water Density Currents, a Major Cause of Siltation in Estuaries," Technical Bulletin No. 2, Corps of Engineers, U. S. Army (April 1957), p. 15.

# SAVANNAH ESTUARY ENVIRONMENTAL RADIOLOGICAL SURVEY (SEERS) PROJECT

by
Julius J. Sabo,[1] John P. Baptist[2], and Fred G. Rueter[3]

## Introduction and Problem

At present, the coastal waters of the United States are being used and no doubt will continue to be used as the receiving media for radioactive wastes discharged from nuclear installations based on land and from those based on marine vessels. Generally the quality of the coastal waters has not been too adversely altered by many of the man-made wastes which usually find their way into these waters; their quality, however, could be seriously affected by receiving radioactive wastes which could create a radiological hazard not only to the aquatic environment but also to man himself.

The United States Navy has several nuclear-powered vessels, all of which use estuarial and other inshore waters. Present operational plans seem to indicate that the nuclear-powered ship, NS Savannah, will sail not only in the coastal waters but also in certain navigable estuaries. The probability is great that more nuclear-powered vessels will become commissioned, and that more land-based nuclear installations will be located near the ocean. If the radioactive wastes from all these nuclear power plants should enter the marine environment, what will be the changes effected upon this environment? What methods can be used to measure these changes? What will be the ecological significance of these changes? How can these receiving waters be used sanitarily to accept the radioactive wastes? These and many other questions should be answered before any significant nuclear program be undertaken near the coastal areas.

The present symposium has been arranged not only to seek answers for the questions just asked, but also to discuss

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the radiological aspects of estuaries in general and the Savannah River Estuary in particular. Many radiological studies of an aquatic environment have been conducted, but only a few have dealt with estuaries. The Division of Radiological Health, Public Health Service, has many aims that it desires to accomplish by guiding a cooperative radiological survey and study of the Savannah Estuary. A cooperative project, such as this Savannah study, is desirable in order to obtain useful data with a minimum of effort. The analysis of water, sediments, and seafood by the Public Health Service;[4] the study of silt deposition and tidal flow by the Corps of Engineers; and the ecological studies by the Bureau of Commercial Fisheries will together contribute more data as to what is occurring in the estuary than could be contributed by any one of these agencies. It is by such mutual exchanges of ideas and interests that these agencies will be able to accomplish many of their aims and ultimately effect methods which will enable investigators to enter an area where a nuclear incident has occurred and evaluate quickly the extent of radioactive contamination.

The Savannah project represents one of the few radiological estuarial studies conducted by the Division of Radiological Health (DRH), PHS. For this reason, we of the Division can relate only what we have so far accomplished by the current survey of the Savannah Estuary and what we plan to do in the survey. The general reason for conducting a radiological study of the estuary is that the Savannah River Plant, a nuclear facility located on the banks of the Savannah River approximately 130 miles upstream from the estuary, discharges some of its liquid radioactive wastes directly into the river. We are concerned with how much of these will reach the estuary, an active fishery, and what ecological influences the wastes will have upon the estuarial aquatic environment.

## Purpose of Radiological Study

The specific purposes for which this estuarial project has been designed are the following:

1. The establishment of baseline radiation levels to which future radiation levels of the Savannah Estuary can be referred. Such a baseline could be used as part of a monitoring system designed

[4] The collection of the various marine samples was made possible by the use of boats provided and manned by U. S. Coast Guard personnel stationed at Savannah, Ga.

to aid in controlling the radiation levels of this marine environment.

2. The derivation of data which can be used to determine the fate of radionuclides in marine waters and which can be used to develop mechanisms capable of removing radionuclides from these waters.

3. The determination of appropriate indicator organisms or other organic materials which can be used in measuring the concentration of radionuclides present in a marine environment.

4. The ascertainment of the effect of radioactive wastes on the fisheries industries.

It is the contention of radiobiologists associated with the Bureau of Commercial Fisheries that on-site natural radiological studies are needed to corroborate laboratory studies. The Savannah Estuary study seems to afford the opportunity for such a corroboration. One can almost consider this aspect as the fifth purpose for conducting the proposed estuarial program.

## Scope of Study

Radiobiologists, in general, are convinced that ecology is an integral element in radiological investigations of estuaries, mainly because estuaries are generally so complex, with thousands of species of organisms living in many different habitats. These species include swimming organisms, plankton, and the benthic organisms.

Progress in ecological studies concerned with radiological aspects has been made by several investigators. Their field and laboratory studies have yielded much useful data on the fate of many radionuclides associated with the aquatic environment. Davis et al. (5) found that suckers in the Columbia River which fed on sessile algae accumulated more radioelements than did other fish of higher trophic levels. The distribution of $Cs^{137}$ has been traced through a fresh water community by Pendleton and Hansen (6). Baptist and Price (2) demonstrated that the growth rate of flounders influenced the rate of $Cs^{137}$ uptake as based on a unit weight of the organisms. Boroughs et al. (3) reported that postlarval flounders accumulated $Sr^{89}$ at a faster rate at 20° C than at 10° C. The use of biological indicators to indicate the presence of radionuclides which

otherwise would not be detectable in the environment has been suggested by Rice and others (10, 11).

The Savannah Estuary, as indicated by figure 1, is a very large and complex system of meandering creeks. Many of the creeks, being contiguous with the river, could receive radioactive wastes should such wastes be present in the river. Fifteen tentative sampling stations have been selected, their choice being based on either ecological or radiological concepts or both. Four of these stations are on the river proper. Other stations are located on many of the smaller creeks, which are highly productive biologically; some are active shrimp nursery areas. Some stations were selected to include areas of either high or low salinity. The South Channel contains a spoil area which receives sediments from the dredged channel. A station near this spoil area was considered to be a good choice for the collection of bottom organisms.

The modus operandi for the ecological study of the Savannah Estuary follows a plan based largely upon advice given by the Bureau of Commercial Fisheries. Such a plan is desired for conducting radiological studies of the following:

1. Water
2. Intertidal region
3. Plankton
4. Swimming organisms
5. Bottom organisms and associated sediments

Similar radiological studies of a control area are being conducted simultaneously with the Savannah studies so that proper evaluations of the latter can be made. The control area is represented by the estuarial waters located at Edisto Beach, North Carolina, about 60 miles northward from the Savannah Estuary.

## Water Study

Water characteristics such as dissolved oxygen, nutrient content, temperature, radioactive content, turbidity, and salinity are known to affect the accumulation of radionuclides by aquatic organisms. For example, some organisms are known to accumulate radionuclides faster at high temperatures than at low temperatures; oysters have been found to accumulate smaller amounts of radioelements when salinities were above or below the normal range;[5] radioactive uptake by some

[5] Unpublished data derived by Thomas J. Price, Bureau of Commercial Fisheries Biological Laboratory, Beaufort, N. C.

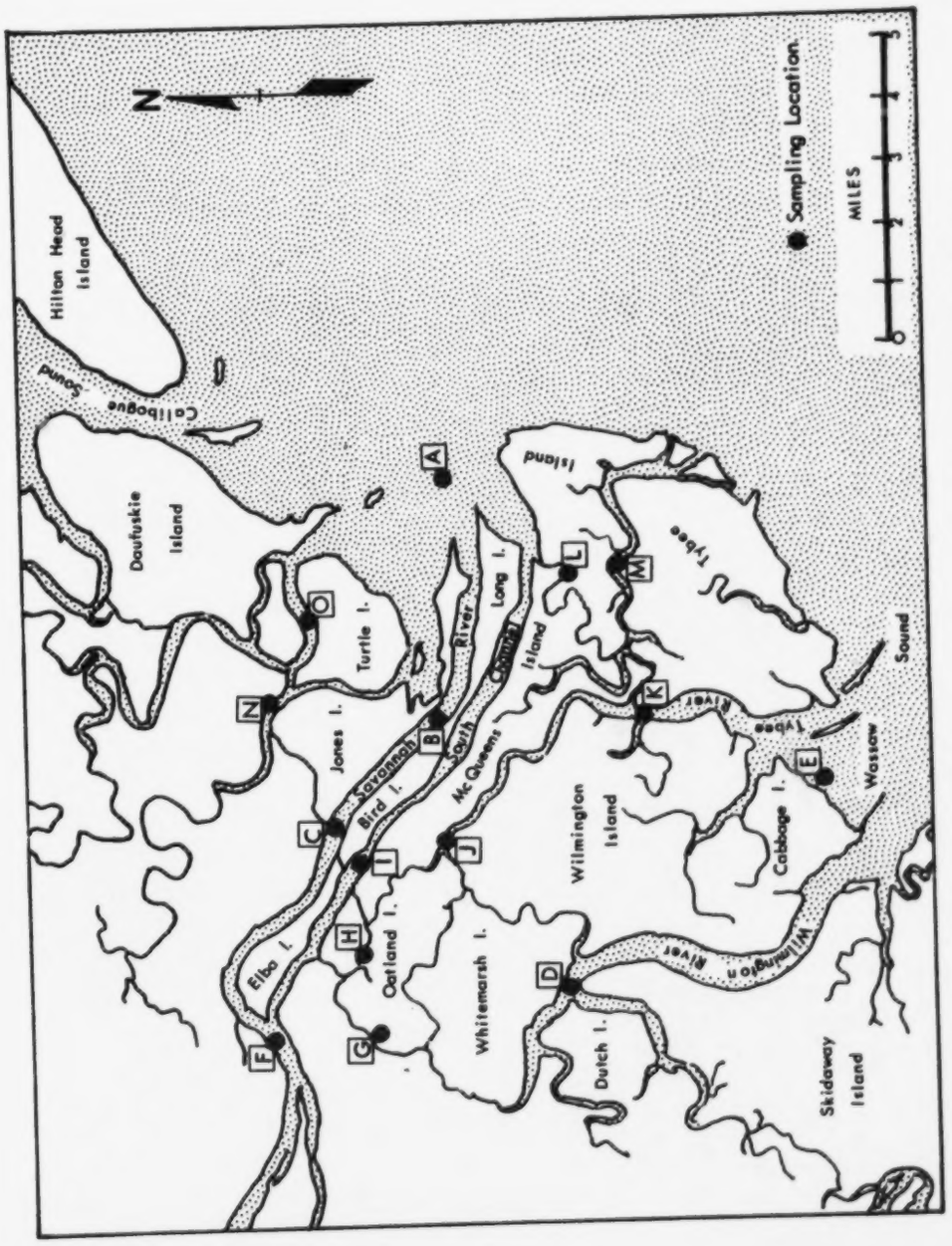


Figure 1.-Location of Sampling Stations in the Savannah Estuary

phytoplankton is so influenced by turbidity interferences, which affect photosynthesis, that the rate of planktonic cell division is altered. Similarly, the lack of nutrients can limit phytoplankton production and result in a decrease in the rate of removal of certain radionuclides from the water. The dissolved oxygen content of water determines to what extent the water will support life. Oxygen determinations, therefore, are important in tracing the cycling of radionuclides in the aquatic environment. Pertinent hydrological data collected by the Corps of Engineers are also being utilized to aid in the explanation of this cycling.

Water samples are sent to SERHL[6] where their suspended and dissolved solids are isolated so that the radioactive content of each group can be determined. Dissolved solids are analyzed by methods of chemical separation. Analyses of the other water characteristics are made by the Bureau of Commercial Fisheries at its laboratory located at Beaufort, North Carolina.

### Intertidal Study

The intertidal region offers much to be studied that is not found in the subtidal region. Since intertidal organisms such as oysters, clams, seaweed, and microscopic algae are alternately exposed to water and air during the tidal cycle, they might be expected to effect less radioactive uptake than organisms which are continuously exposed to water. However, their usefulness as indicators of radioactive contamination is enhanced by their being predominantly sessile and easily accessible for examination (see figure 2). Tentative plans have been made to investigate the estuarine communities of organisms inhabiting rock jetties, dock pilings, sand bars, and oyster reefs. Organisms of the tidal zone are probably instrumental in the transmission of radionuclides through certain food chains. During high tide, active animals such as fishes and crabs move into the tidal zones in search of food. During low tide, terrestrial animals such as mink, rats, and skunks feed on these tidal organisms. Thus, tidal zones are involved in the food chains of two different environments.

Oysters, which are major organisms in the intertidal region, have been sampled and analyzed after being separated into flesh and shell components (figure 3). This separation was necessary because the flesh had a radioactive content which was much greater than that of the shell; all of the shells contained less than 2.4 pc/g ash. Further, the oyster flesh was more easily analyzed separately than in combination with the shell. Before oysters were sent to SERHL for analysis, they were prepared in the field in accordance with the following procedure:

1. Oyster shells were wire-brushed clean of algae and mud.

2. Oysters were then pried open and the mantle liquid was drained and discarded.

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[6] Southeastern Radiological Health Laboratory, Montgomery, Ala. This laboratory is operated by the Division of Radiological Health, Public Health Service.

Figure 2.-Collection of Oysters from One of Several Sampling Sites Along the Savannah River in the Estuarine Area

3. The oyster flesh together with the body liquids were shucked into a polyethylene bottle containing a 70 percent ethyl alcohol preservative. All organic samples were so preserved.

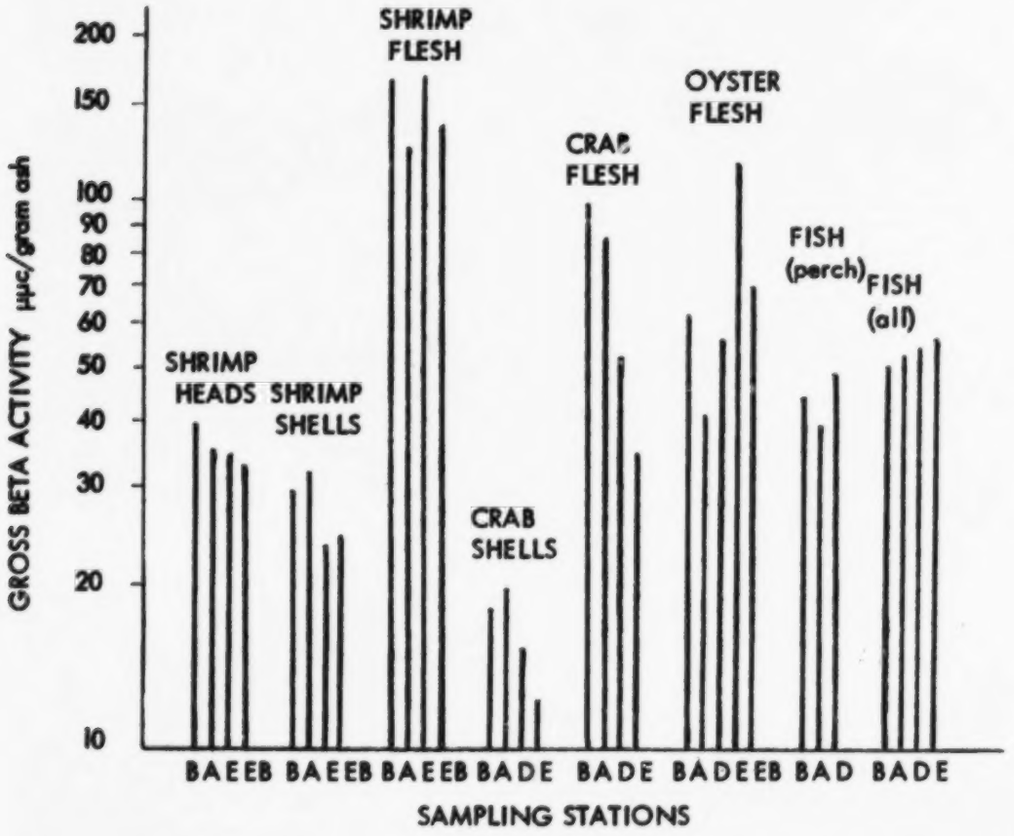


**Figure 3.–Gross Beta Radiation Levels for Various Organisms Collected from the Savannah Estuary at the Designated Sampling Stations (NOTE: Some organisms were analyzed in their entirety; others were analyzed in their separate parts.)**

## Plankton Study

Plankton are of great importance because of their position at the beginning of food chains and because of their capacity for concentrating most radionuclides. Phytoplankton, being autotrophic, obtain nutrients from the water and are able to produce energy through the process of photosynthesis. Phytoplankton are fed upon by shellfish and zooplankton, the former representing a single link in the food chain extending from a primary producer to a seafood organism. Fish, according to their species, may represent the second, third, or fourth link of the food chain.

Identification and enumeration of phytoplankton is accomplished by microscopic examination of measured volumes of

the sampled water. This method yields a quantitative count; other methods are gravimetric and probably will not be effective because of the presence of considerable silt associated with the water. Identification of plankton is more important than may appear, since some are known to concentrate $Sr^{89}$ about 100 times more than others (9). Thus, by knowing which plankton species predominate in an area, one can make an approximate prediction as to which nuclides will be available to other organisms. Zooplankton, including larval forms of insects, molluscks, crustaceans, fish eggs, etc., accumulate radionuclides by feeding primarily on phytoplankton and on the dissolved nutrients present in the ambient water. Rice and Murdoch (11) reported concentration factors of 200 for $Zn^{65}$ and approximately 600 for $Ce^{144}$ in the copepod, Tigriopus. They also reported that Artemia accumulated 2.6 times more $Zn^{65}$ from food than from water and 7.5 times more $Co^{56, 57, 58}$ from food than from water. Thus, zooplankton have two pathways of accumulation, and since they are food for primary carnivores of the third tropic level, zooplankton play a very important part in the transmission of radionuclides.

## Swimming Organisms

The study of swimming organisms has been underway at some stations. Organisms of many species have been collected for radiological analysis and have also included non swimmers such as sponges, corals, starfish, jellyfish, squid, and other organisms that were present in sufficient number so as to comprise a radiological sample (see figures 4 and 5). It is hoped that this collection approach might lead to the discovery of suitable biological indicators which can be used to measure local radioactive contamination. At the present time, such indicators include fish shorter than 6 inches, shrimp younger than 6 months, and blue crabs. To measure the radioactive contamination of a general aquatic area, shrimp older than 6 months and large fish may be used as the indicators.

It has been found from examinations made by the Public Health Service (graphed in figure 3) that fish can be effectively radioassayed in their entirety. Shrimp, however, have to be divided into three portions: the head with viscera, the flesh, and the shell, since the flesh portion was found to contain more radioactivity per gram of ash than the other portions of the animal. Further, the ashed flesh represented less than 20 percent of the total ashed weight; therefore, the high radioactive

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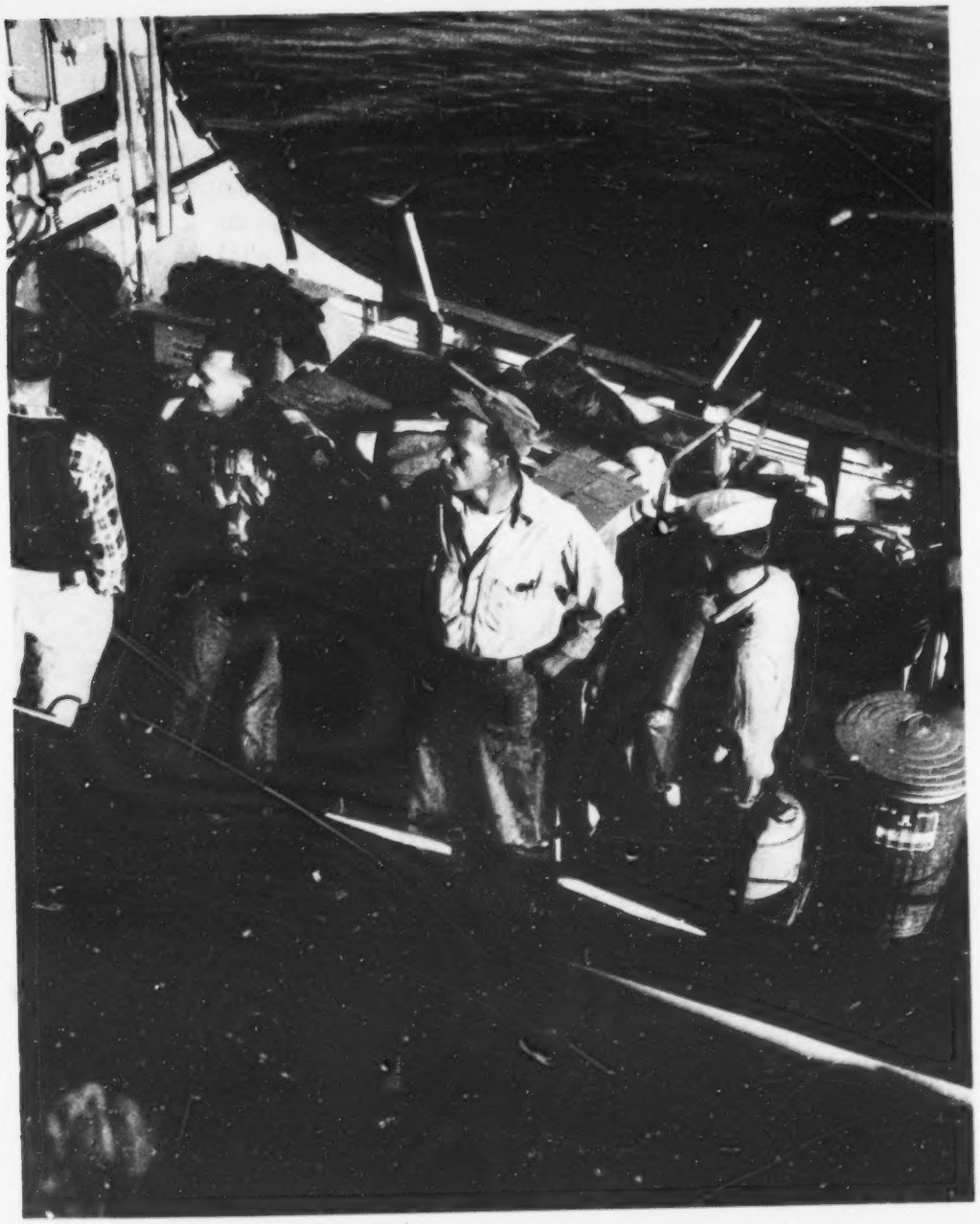

Figure 4.-Men, Boat, and Sampling Equipment Used in the Collection of Marine Samples from the Offshore Waters

concentration found in the flesh would have been diluted had the shrimp been analyzed in its entirety. For this reason it is considered that the shrimp flesh is a more sensitive indicator than the whole shrimp. A similar finding was made in the case of crabs (primarily blue crabs). The crabs were

Figure 5.-Collection of Fish from the Deep Offshore Waters

steamed before ashing because the steamed crab flesh was easier to handle and easier to separate from the shell than the raw flesh. The ashed weight of the steamed crab flesh was found to be about 15 percent of the total ashed crab weight, while the activity per gram of ashed flesh was more than 3 times that of the shell portion; hence, the flesh alone seems to be the better indicator.

Stomach contents of the various organisms have not been examined, but they will be in order to obtain food chain data which can probably be related to the transmission of radionuclides. Examination of the contents from the digestive tracts of organisms is most useful in identifying the food eaten by the organisms; however, unless the animal is examined soon after it has eaten, identification of the ingested forms is extremely difficult. By examining large numbers of specimens at different times this difficulty may be overcome to some extent. Fish of certain species are known to change their food habits during their developmental phases. For example, the menhaden (Brevoortia tyrannus) is a filter feeder in the juvenile and adult stages, but a particulate feeder in the larval stage (4).

Since the growth rate of an organism affects its uptake of radionuclides, such rates are needed for the various species in order to evaluate properly the radiobiological findings. Animals with fast growth rates tend to show decreased amounts of radioactive material per unit weight by reason of "biological dilution" if the material is not essential for metabolism (2).

### Benthic Organisms and Sediments

The role of benthic organisms in the cycling of radionuclides is closely related to the bottom sediments, which rapidly accumulate certain radionuclides. For example, Pendleton and Hanson (6) reported that a large part of the $Cs^{137}$ in an aquatic community was adsorbed on the sediments. Many benthic organisms such as worms and crustaceans ingest sediments and hence radionuclides along with their food. Anderson et al. (1) reported considerable amounts of clay in the guts of mullets, anchovies, and menhaden. Shellfish are especially susceptible to radioactive contamination since radioactive material is available to them from water, plankton, and the substrata.

Since the type of bottom material helps to control the benthic animal communities, sediments have been collected and screened in order to collect the organisms present. Some silts and bottom muds have been separated into their various size fractions for radiological examination. The fractions below the 60 micron ($\mu$) size were separated by sedimentation, whereas fractions above this size were separated by wet sieving. The size fractions so prepared were then sent to SERHL for analysis. All sieving and separation were accomplished hydraulically as described in the following paragraphs.

Collection of bottom muds was made with an Eckman dredge, which so far has shown satisfactory performance. Ten to 15 gallons of water, hereinafter referred to as "local" water, were collected with each of these mud samples and from approximately the same sites as those of the muds. Until such time as they could be analyzed, each mud sample, moistened with a sufficient amount of its local water, was stored in a sealed polyethylene container. There might be some interest in obtaining bottom mud cores to see if a gradient of radioactivity versus mud depth does exist. Such a gradient is expected not to be present in situ in freshly mixed muds and silts; however, in areas where recent mixing has not taken place, the movement of radionuclides through the sediment might establish an activity gradient.

The wet sieving process, shown schematically in figure 6, was conducted on a few sampled sediments by placing the sediment on the topmost sieve and then washing the sediment with its local water through each of the sieves until separation was complete and sediment particles of less than 60μ size were left in the mud-water reservoir. A recycle pump was used for the complete washing of the sediment. Local water only was used for the washing so as to preserve as much as possible the in situ characteristics of the clays, silts, and flocculents that are usually present in muds. In the actual sieving, the mud sample was not washed through a series of fixed sieves, but was washed through succeeding sieves with each sieve being used singly because the agitation required for sieving was more effectively applied with the single sieve than with the stacked series. Table 1 lists the serial gradations for the standard mesh sieve sizes. The Wentworth Particle Size Designation is one of the established classifications relating the size designation to a size term.

The material remaining on the 3.3 millimeter (mm) and 2.0 mm screens (mesh 6 and mesh 9 sieves) was discarded because it usually consisted of shell fragments, driftwood, and other organic material. The materials which remained on the other screens, after each complete washing, were transferred to polyethylene containers and covered with enough local water to retard drying until such time as these materials could be analyzed. The fine materials which had passed through the 60 μ sieve (mesh 250) do not lend themselves readily to size analysis by sieves; thus, a sedimentation process based upon a consideration of terminal velocities was used for these. Terminal velocities were determined for the fine particles by using a simplification of Stokes' equation together with related

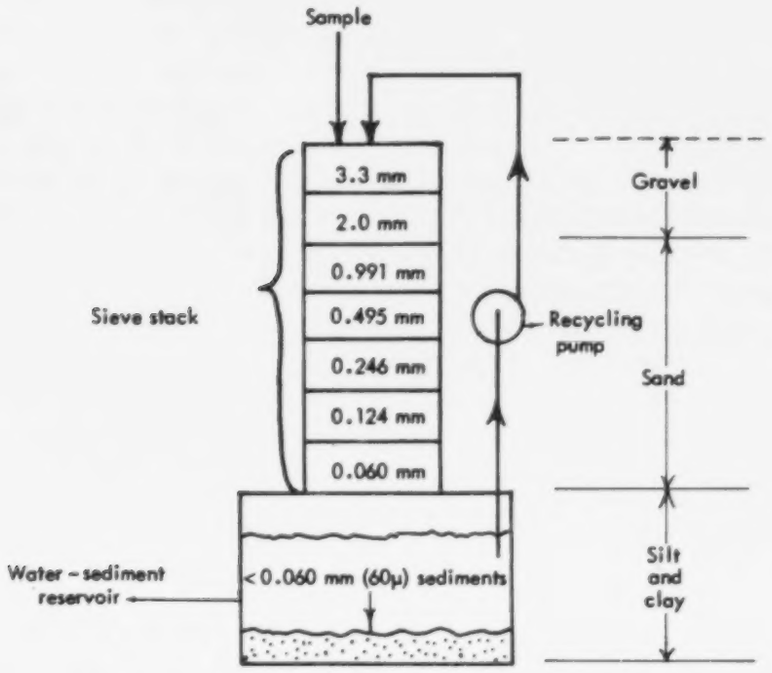


**Figure 6.-Sketch of Wet Sieve Equipment and its Operation**

correction factors. The assumptions used to simplify Stokes' equation are as follows:

1. Sediment particles were assumed to be spherical.

2. Specific gravity of the brackish dispersion water was assumed equal to that of fresh water.

3. Specific gravity of 2.7 was assumed for the mud sample.

Table 1.-Particle Size Designation and Sieve Size (8)

| Wentworth Particle Size Designation | Sieve size openings | |
|---|---|---|
| | Millimeters | U.S. standard mesh |
| Pebbles | 3.962 | 5 |
| Granules | 3.327 | 6 |
| Very coarse sand | 1.981 | 9 |
| Coarse sand | 0.991 | 16 |
| Medium sand | 0.495 | 32 |
| Fine sand | 0.246 | 60 |
| Very find sand | 0.124 | 115 |
| Silt | 0.061 | 250 |

For a more accurate and precise determination of terminal velocities, the above three factors should be actually determined and not assumed; however, for the purposes of this study, the assumptions were quite adequate.

Two methods of size separation can be used in the sedimentation process. One, a static method, was used in this project; the other, a dynamic method, is conceptual only. The first step of the static method, shown schematically in figure 7, involved the thorough mixing of the sediment and then allowing the mixture to settle until most of the coarse material had settled from the mixture. The fines which had not settled were then siphoned from the upper portion of the suspension and were further separated by the technique illustrated in figure 7. The coarse material which had settled was reclaimed for the second step. The settling time for the fractions being separated was based upon their calculated terminal velocities (see table 2).

Table 2.-Terminal Velocities for Spherical Particles (Assumed Specific Gravity of 2.7) in Pure Water at 20° C (7)

| Wentworth Particle Size Designation | Particle size (millimeters) | Terminal velocity | | Time to settle 5 cm |
|---|---|---|---|---|
| | | ft/sec | cm/sec | |
| Fine sand | 0.124 | $3.8 \times 10^{-2}$ | 1.16 | 4.3 sec |
| Very fine sand | 0.060 | $1.1 \times 10^{-2}$ | 0.335 | 14.9 sec |
| Silt | 0.030 | $2.8 \times 10^{-3}$ | 0.0853 | 58.6 sec |
| | 0.015 | $7.2 \times 10^{-4}$ | 0.0219 | 3 min 48 sec |
| | 0.0075 | $1.4 \times 10^{-4}$ | 0.00427 | 19 min 23 sec |
| | 0.0039 | $4.5 \times 10^{-5}$ | 0.00137 | 60 min 49 sec |
| Clay | | | | |

In the second step, the remaining coarse material was mixed and allowed to settle for a shorter time as determined by the terminal velocity of the next larger size fraction, as shown in table 2. Again the top material was siphoned off. This latter separation produced fines which in themselves had to be separated by using the first step of the sedimentation technique as already outlined.

The dynamic procedure is being developed because the wet sieving process proved to be cumbersome and inadequate for the separation of particles equal to or less than 0.5 mm and somewhat cumbersome for the separation of the larger particles. The dynamic procedure, it is anticipated, will accomplish more

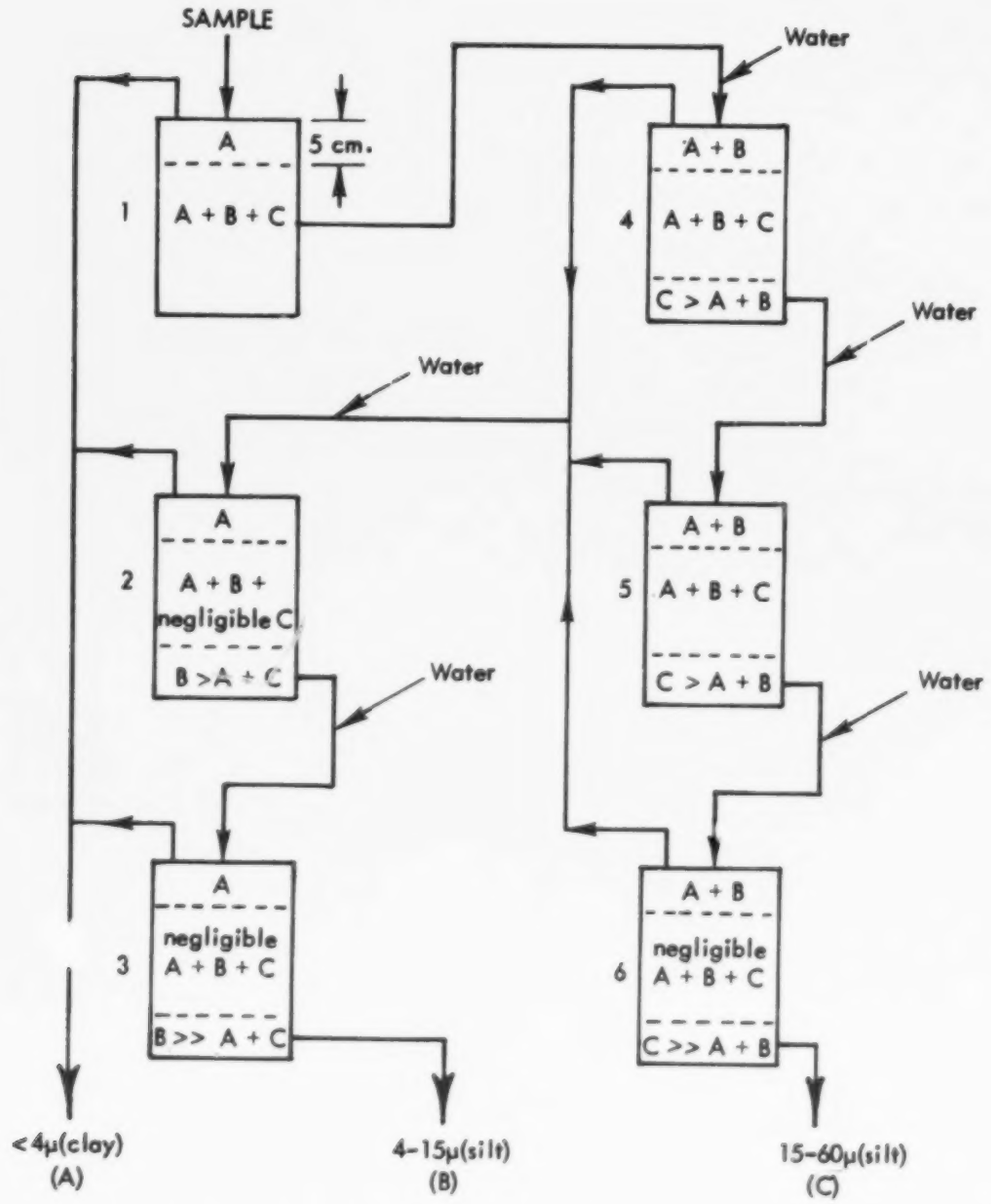


Figure 7.-Flow Sheet for the Static Method of Sediment Separation (Note: Operations 1, 2, and 3 each use a settling time of 1 hr. 49 sec.; operations 4, 5, and 6 each use a settling time of 3 min. 48 sec.)

effectively what the complete wet sieving and sedimentation process could accomplish only with difficulty. In the design of the equipment for the dynamic process, 5 elutriation columns are to be arranged in successive gradations, with the smallest diameter column being first and the largest one last. Figure 8 shows a schematization of the equipment and a flow diagram of how a sediment sample is to be ideally separated by this process.

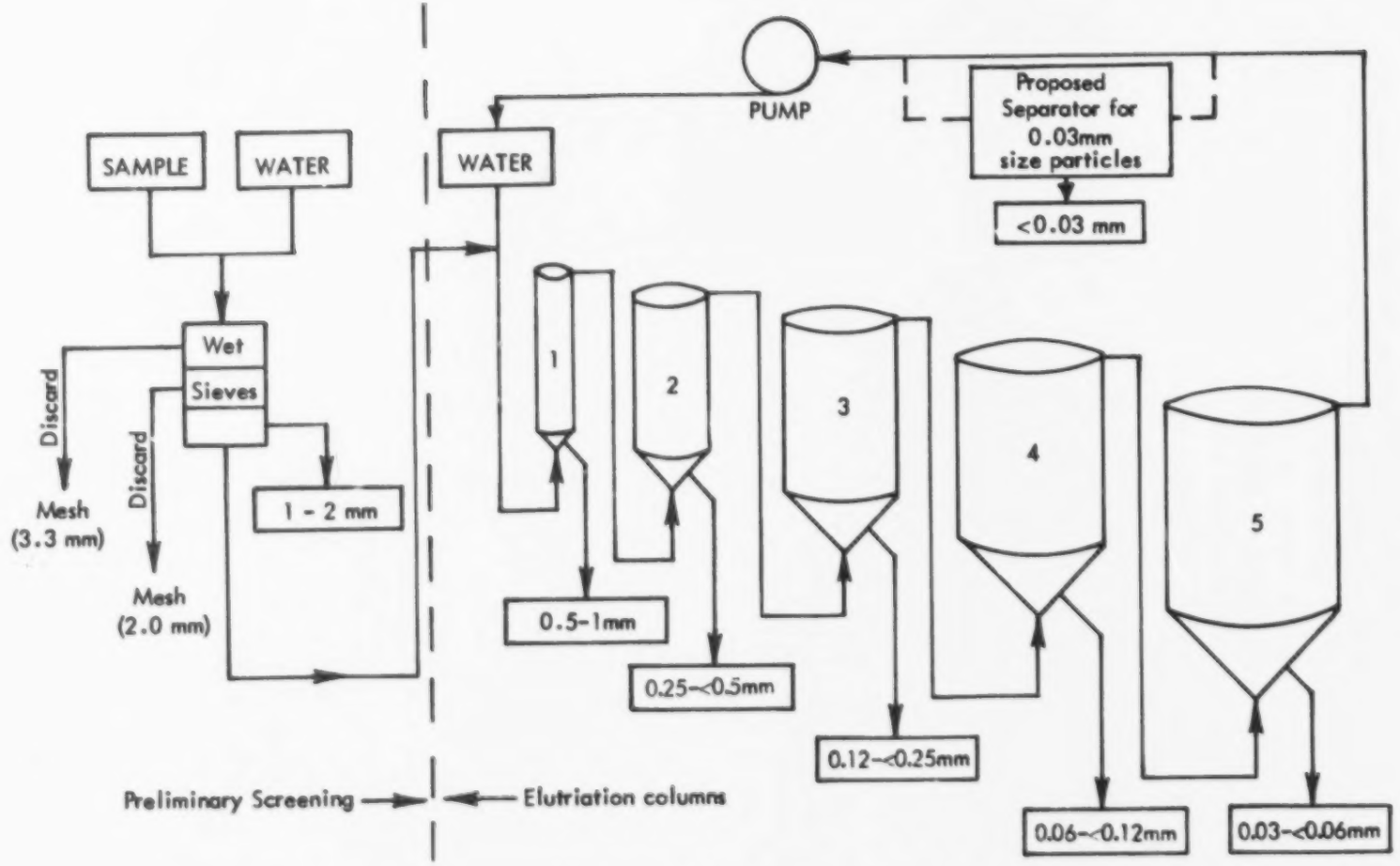


Figure 8.-Flow Sheet for Size Separation of Bottom Sediments Using Elutriation Columns

The mud sample, containing particles no larger than the 1 mm size after preliminary screening, will flow with its local water into the bottom of the first cylinder. This flow rate has been so selected, and the diameter of the first cylinder so designed, that particles < 0.5 mm in size will be flushed up through the first cylinder and introduced into the bottom of the next larger cylinder. The particles remaining in the first cylinder will be collected at the end of the process and will constitute the $\leqq$ 1.0 to $\geqq$ 0.5 mm-size sample. The second cylinder is also of such a diameter that for the chosen flow rate, particles < 0.25 mm will flush over the top and into the third cylinder. Particles in the size range < 0.5 to $\geqq$ 0.25 mm will remain in the second cylinder and so constitute the sample for this size fraction. The procedure will continue through the remaining three cylinders of progressively larger diameters, with a particular sized sample remaining within each cylinder for removal at the end of the process. The largest cylinder will retain the particles 0.03 to 0.06 mm in diameter. The 0.03 mm-size particle is about the smallest particle that can be practically separated by using the dynamic elutriation column. At present no workable method has been developed that will remove the < 0.03 mm-size particles from the recycled stream at the designed flow rate. Thus, with the continuous recycling, there will be some contamination of each separated fraction by the < 0.03 mm-size material. This contamination should present no problems because a large amount of local water is to be used; thus, the < 0.03 mm-size material will be well dispersed. As soon as the elutriation columns are constructed and tried, efforts will be directed toward the designing of a practicable method for removing the < 0.03 mm-size material from the flow stream.

## Data Analysis

To date, only 3 months' analytical results have been produced from the estuarial survey. As more results become available, it is hoped that an evaluation of geographical effects can be made from an examination of these data. Also, it is desired to compare in due time the concentrations of radioactivity measured at each station so as to determine seasonal cycles which may exist. Refinements or changes of sampling methods, of sample analyses, and of any other aspect of the survey will be made as indicated by valid interpretations of all the survey data.

Radiological data which have been derived from the estuarial study are represented by the bar graphs shown in figure

3. The stations designated on each of the graphs are arranged from left to right to follow closely the actual downstream sequence. There appears to be a trend of decreasing activity in a downstream direction; however, this trend is so slight that its significance is questionable.

One desired result of the SEERS Project is to collect and tabulate the radiological data of the Savannah Estuary in such a form that they can easily be compared with similar data from other areas. The Savannah data have been recorded on cards which are filed by project code and by the type of sample analyzed. These cards contain the following information: location, sampling station, fraction of sample, type of sample, sample number, date of collection, laboratory sample number, date of analysis, $\alpha$, $\beta$, and $\gamma$ activities. This method of data handling became rather unwieldly after the accumulation of a number of sample results; thus a change was made to cards of the Keysort System. These Keysort cards have the same data typed on them, as well as the location, sampling station, fraction of sample, type of sample, and sample number coded and punched in the fields located around the edges of the cards. With this system the cards need not be filed in categories, for the desired information can be easily found by use of the code and the perforated fields along the sides of the cards. This method has an increased capacity over the former card filing system; however, even the Keysort System becomes cumbersome when the number of results exceeds 1,000. With this limitation in mind, it was decided that the final system should employ high speed punched cards and computer equipment.

The use of a computer is greatly simplified if all data are supplied in a standard form. To facilitate this, a source document was designed for use in the total flow of data from field sampling to computer programming. This source document has undergone several revisions and no doubt will be revised many more times before the final form is acceptable for all phases of data flow. The present form of the source document is shown in figures 9 and 10. The coding has been worked out by Mr. Paul D. Eckrich and others and is available at Technical Operations Branch, Division of Radiological Health, Radiological Health Laboratory, Rockville, Maryland. It should be mentioned that this coding, together with the source document, has been developed for all types of environmental sampling and not just estuarial sampling. Thus, by using such a source document, almost all environmental data can be analyzed by automatic data processing equipment.

**ENVIRONMENTAL RADIATION SURVEILLANCE REPORT**

FIELD DATA

CARD #1 1. Sample Number (1 2 3 4 5 6)

2. Type of Sample (7 8 9)

3. Fraction of Sample (10 11)

4. Card Identification (do not use) (12 13)

5. Location _____ (14 15 16)

Station _____ Substation _____ (17 18 19 20)

6. State _____ County _____ (21 22 23 24 25)

City _____ (26 27 28)

7. Date Sampled (29 30 31 32)

| | | | |
|---|---|---|---|
| Weight of container and sample | | Weight of container and sample and preservative | |
| Weight of container | | Weight of container and sample | |
| Weight of sample | | Weight of preservative | |

LABORATORY DATA

8. % ash _____ (33 34 35 36)

% moisture _____ (37 38 39 40)

weight ash _____ (41 42 43 44 45)

method of ashing used _____

9. Number of analyses made on this sample (46 47)

10. Type of analysis _____ (48 49 50 51 52)

1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight
6. μμc (total ash weight)
7. μμc/kilogram natural weight
8. grams/gram ash x $10^{-1}$
9. Other (specify)

(53 54 55 56 57)

_____ ± _____ (58 59 60 61 62)

(circle correct units)

11. Type of analysis _____ (63 64 65 66 67)

1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight
6. μμc (total ash weight)
7. μμc/kilogram natural weight
8. grams/gram ash x $10^{-1}$
9. Other (specify)

(68 69 70 71 72)

_____ ± _____ (73 74 75 76 77)

(circle correct units)

Department of Health, Education & Welfare, PHS, Div. of Rad. Health

12. Project Identification (E 79 S 80)

Figure 9.-Sample Form for the First Page of a Typical Source Document

ENVIRONMENTAL RADIATION SURVEILLANCE REPORT

CARD # ____ SAMPLE NUMBER [ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ] 1 2 3 4 5 6 7 8 9 10 11 12 13

LABORATORY DATA

ITEM # ____
Type of Analysis _____ [ ][ ][ ][ ][ ] 14 15 16 17 18
1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight [ ][ ][ ][ ][ ] 19 20 21 22 23
6. μμc (total ash weight)
7. μμc/kilogram natural weight
_____ ± _____ 8. grams/gram ash x $10^{-1}$
(circle correct units) 9. Other (specify) 24 25 26 27 28

ITEM # ____
Type of analysis _____ [ ][ ][ ][ ][ ] 29 30 31 32 33
1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight 34 35 36 37 38
6. μμc (total ash weight)
_____ ± _____ 7. μμc/kilogram natural weight
(circle correct units) 8. grams/gram ash x $10^{-1}$
9. Other (specify) 39 40 41 42 43

ITEM # ____
Type of Analysis _____ [ ][ ][ ][ ][ ] 44 45 46 47 48
1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight 49 50 51 52 53
6. μμc (total ash weight)
_____ ± _____ 7. μμc/kilogram natural weight
(circle correct units) 8. grams/gram ash x $10^{-1}$
9. Other (specify) 54 55 56 57 58

ITEM # ____
Type of Analysis _____ [ ][ ][ ][ ][ ] 59 60 61 62 63
1. μμc/liter
2. μμc/cubic meter
3. μμc/gram ashed weight
4. μμc/gram drained weight
5. μμc/gram dried weight 64 65 66 67 68
6. μμc (total ash weight)
_____ ± _____ 7. μμc/kilogram natural weight
(circle correct units) 8. grams/gram ash x $10^{-1}$
9. Other (specify) 69 70 71 72 73

REMARKS: (refer to item number)

Department of Health, Education & Welfare, PHS, Division of Radiological Health | 6. Project Identification [ E ][ S ] 79 80

Figure 10.-Sample Form for the Second and Succeeding Pages of the Typical Source Document

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# ACCUMULATION OF RADIONUCLIDES BY AQUATIC ORGANISMS

by

T. R. Rice

Chief, Radiobiological Program, Bureau of Commercial Fisheries Biological Laboratory, Beaufort, North Carolina

Laws have been established to govern waste disposal practices and health regulations so as to protect man's environment. These laws do not permit a deliberate contamination of an estuary with radioactive materials. To implement these regulations the Radiobiological Program at Beaufort is endeavoring to collect sufficient data that can be used to predict the dangers to aquatic organisms which could arise from an intentional or accidental release of radioactive wastes into an estuary or an ocean area. In order to obtain accurate representative data it is necessary to compare the data obtained in the laboratory with data obtained from a natural environment. For this reason the cooperative program on the Savannah Estuary sponsored by the Public Health Service and the Bureau of Commercial Fisheries is a satisfactory arrangement, since this program allows for a comparison of laboratory data with field data. In addition to data comparison, a transition from laboratory to field conditions will be obtained by studies on presently polluted estuaries and from controlled experiments in tanks and ponds. These controlled experiments can be referred to as pilot-model experiments and serve as a testing area for certain questionable findings arising from laboratory experiments. By using tanks and ponds, the desired isotope in the required quantities can be followed after introduction into the water; competition among organisms for this material can be observed, and the pathways in the food web taken by a particular radioisotope can be identified.

When the Maximum Permissible Concentrations (MPC's) were calculated for the different radionuclides which occur in drinking water, the assumption must have been made that such concentration of radionuclides in the aquatic environment would result in not only an insignificant return of activity to man, but would also be of no harm to aquatic organisms. This assumption has not been validated and will require the collection of considerable data before any confidence can be attached to it. Radionuclides in these permissible concentrations may

adversely affect aquatic organisms which are used as food by man, or reduce the population of other organisms in the food web, thereby reducing the availability of food to man. It is known from experimental evidence that certain organisms, in addition to those of commercial value, serve as a vital link in certain food webs and can concentrate some radioisotopes to levels much greater than those occurring in the ambient water. The damaging effect that these concentrated radiation levels might have on the organisms must be determined.

With the expanding nuclear energy industry which has developed in less than 15 years, man will probably find that keeping his environment free from radioactive pollution will be more and more difficult. Thus a responsibility rests upon those who pollute the environment with these materials and upon those who must protect human health and insure the safe-keeping of the living resources. Since it is definitely impracticable, if not impossible, to insure that no radioactivity will get into the environment, levels that are safe and rates at which radionuclides can be added to the aquatic environment must be known.

Since the amounts of the different radionuclides that can occur in the human body without undue danger are known, calculations can be made of the permissible concentrations of radionuclides which can occur in food, air, and water. If radioactivity reaching man comes from only one of these three sources, the concentration of radionuclides in that source may be larger than if the radioactivity came simultaneously from all three. If the only source of radioactivity to man from a particular aquatic environment is drinking water, it becomes relatively easy to make measurements on the water and keep levels below the MPC. However, should plants and animals from this area be used as food, then the extent to which they concentrate the different radionuclides must be known.

The organisms which concentrate a radionuclide to the highest degree are not necessarily the controlling factors in the disposal of radioactive wastes. Rather, the organisms which concentrate the radionuclide to the highest degree in relation to the amount eaten by man will be more important. For example, at Windscale, England, an exhaustive program was undertaken to study the principal bottom fish, a plaice, Pleuronectes platessa, andto determine its role in the passage of radionuclides to man (3, 4, 5). Movements of this fish were determined by tagging, and laboratory investigations were performed in which fish were kept in water containing radio-

active materials so that the concentration factor, the ratio of concentration of radioactivity in the water to that of the radioactivity in the various parts of the fish, could be obtained. In spite of these logical studies with the plaice, however, the edible seaweed, Porphyra, which is eaten by man to a greater extent than the plaice, was found to concentrate radionuclides to such high levels that it became the limiting factor in the discharge of wastes from the Windscale Plants. Near the reactor of Winfrith, on the Dorset Coast of England, the lobster was found to be the critical animal limiting the discharge of radioactive wastes (9).

A number of reports have appeared in the literature concerning the occurrence of radionuclides in aquatic organisms used as food by man (10, 13, 18). For instance, the concentration of $Zn^{65}$ in oysters grown in Willapa Bay, Washington, the closest commercial oyster-producing area north of the Columbia River, appears to be substantially higher than in oysters from other areas. However, this higher concentration of $Zn^{65}$ need not concern us greatly; the amount of oysters from Willapa Bay which one must eat in order to obtain the maximum permissible body burden is given in table 1. The calculations are based on $10^{-3}$ microcuries per milliliter (μc/ml) as the maximum permissible concentration of $Zn^{65}$ in drinking water for occupational exposure, which is equivalent to a sustained intake of about 2.2 μc/day assuming that the average person drinks 2200 ml of water per day (12). An average concentration of $Zn^{65}$ in oyster meat from Willapa Bay was taken as $5 \times 10^{-5}$ μc/g. It should be stressed that these data are for sustained consumption and that the maximum permissible body burden associated with these rates will be reached only if intake is continuous for 3 years or more (6).

Table 1.-Amounts of Oysters from Willapa Bay, Washington, Which Must Be Eaten to Obtain the Maximum Permissible Body Burden of $Zn^{65}$ (7)

| Premise | Sustained consumption rate to give exposure of premise |
|---|---|
| Occupational Exposure - Handbook 69 | 700 pounds/week |
| Persons in the neighborhood of controlled areas[1] | 70 pounds/week |
| Suggested I.C.R.P. apportionment for genetic dose[2] | 7 pounds/week |
| Doubling of natural background[3] | 14 pounds/week |

1 Taken as 0.1 of values recommended in Handbook 69.

2 Taking 0.01 of the Handbook 69 values as equivalent to an exposure of 1.5 rem to the gonads in 30 years. It should be noted that the International Commission on Radiological Protection for genetic reasons assumes that the entire population is exposed at this level. The oysters in this case contribute to only a very small fraction of the total population.

3 Assumes that a continuous intake rate of 2.2μc/day results in 5 rem/year to the body and that natural background contributes 100 millirem/year.

In evaluating the health hazard and determining which organism will be the source of the largest amounts of radioactivity, it is necessary to know what radionuclides are present. Also, since all radioactive elements are not equally harmful, it will be necessary to know the amount of radionuclides present in the water and the duration of their presence. If their presence is for only a short period of time, organisms which have high metabolic rates, large surface areas, or mechanisms for rapidly removing the radioactive materials from the water may be the most radioactive after a few hours. Organisms which have slower rates of accumulation but which have higher concentrating capacities could be as radioactive if they were given sufficient time to achieve uptake.

For a few days to weeks following the detonation of an atomic bomb, large numbers of radioisotopes are found in plankton and other aquatic organisms in the vicinity of the explosion. It is not until several weeks later that the number of isotopes becomes limited and an association of specific isotopes with certain organisms and tissues can be established. The distribution of radioisotopes in the biota varies from organism to organism and is strikingly different for aquatic and terrestrial forms. Of the long-lived fission product isotopes ($Sr^{90}$, $Cs^{137}$, and $Ce^{144}$), only $Ce^{144}$ enters significantly into the biological cycle in the marine environment. Of the induced radionuclides, Fe, Zn, Co, and Mn occur in largest concentrations in the biota. Some of the biologically more important radionuclides which either now or in the future may occur in the aquatic environment are listed in table 2.

Radioactive materials introduced into an aquatic environment such as an estuary can either (1) remain in solution, (2) precipitate and settle on the bottom, thereby exposing bottom organisms to more radiation, or (3) be taken up by plants and animals. Thus, three phases exist in such an environment: water, bottom or sediment, and biota. One must understand that factors are in operation which tend to dilute and disperse radioactive materials while simultaneously other conditions are concentrating the radioactive substances (figure 1).

The amount of a nuclide in a unit weight of an organism in relation to the quantity of the same kind of nuclide in an equal unit weight of the organism's ambient water is referred to as the concentration factor. Concentration factors vary with season, concentration of the element in the water, concentration of other metabolically similar elements, age of the

Table 2.-Some of the Significant Radionuclides Which Have Occurred or May Occur as Pollutants in the Aquatic Environment

| Eniwetok-Bikini Area (14) | Columbia River (3) | Waste from nuclear powered ships (2) |
|---|---|---|
| | Arsenic-76 | |
| Cerium-144 | | Cerium-144 |
| Cesium-137 | Cesium-137 | Cesium-137 |
| Cobalt-57, -58, -60 | Cobalt-60 | Cobalt-60 |
| | Copper-64 | Copper-64 |
| | Chromium-51 | Chromium-51 |
| | | Iodine-131 |
| Iron-55, -59 | Iron-59 | Iron-55, -59 |
| Manganese-54 | Manganese-54, -56 | |
| | Neptunium-239 | |
| Niobium-95 | | Niobium-95 |
| | Phosphorus-32 | |
| Rhodium-106 | | |
| Ruthenium-106 | | Ruthenium-106 |
| | Scandium-46 | |
| | Sodium-24 | |
| Strontium-89, -90 | Strontium-89, -90 | Strontium-90 |
| | | Tantalum-182 |
| Yttrium-91 | | |
| Zinc-65 | Zinc-65 | Zinc-65 |
| Zirconium-95 | | Zirconium-95 |

organisms, sex, and a number of other conditions. Many oceanographers have maintained that all one has need for is the concentration factors for the particular radionuclides in as many organisms as possible. With this information, and a measurement of the radioactivity in the water, one can calculate the activity which will eventually occur in the organisms

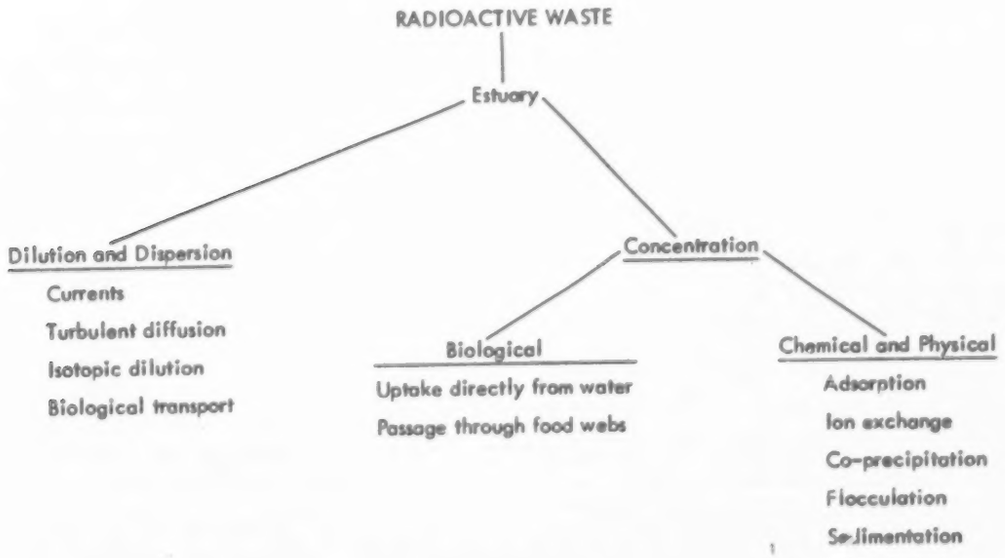


Figure 1.-A Schematic Diagram Showing the Processes Tending to Dilute or Concentrate Radioactive Materials Added to an Estuary

if the level of radioactivity is maintained in the water; one can also calculate the worst conditions that could occur but cannot develop data on concentration rates.

The uptake of a radioisotope depends both upon the metabolic need of the particular organism for the element and upon the amount of radioisotope in the water in relation to the total concentration of the element. Some investigators are of the opinion that the concentration reached by a radionuclide at equilibrium in an organism will be the same whether or not the radionuclide was obtained from water or from food. In our opinion this may not hold true in all instances for all radioisotopes. An experiment with Artemia will demonstrate our point. This organism can live for about 4 to 6 months under the conditions in our laboratory. The experiment was followed for 22 days, or about one-fourth to one-sixth of the organism's lifetime, and there was no indication that the Artemia obtaining $Zn^{65}$ from water would ever contain as much as those obtaining $Zn^{65}$ from food. Another point shown by this experiment is that some small organisms, which may be important accumulators, might not live long enough to reach equilibrium. The rate of uptake, therefore, as well as the source of the isotope, will have a bearing on the eventual concentration reached in the organism.

In our laboratory we found that phytoplankton accumulated every radioisotope present in a mixed fission product mixture when it was added to their culture medium. Also, experiments were run with natural populations of phytoplankton collected from the ocean near the laboratory dock and also 10 miles offshore. These populations when added to the culture medium rapidly removed radionuclides such as $Ce^{144}$.

Whether a radionuclide occurs in an ionic or a particulate state makes little difference in its uptake by plankton. If the nuclide cannot be metabolized by the cells, it may be adsorbed to the surface of the cells. However, such is not the case for the larger organisms which have a disproportionate ratio of surface area to body size. Also, particles usually cannot pass through the living membranes of the larger organisms and cannot, therefore, enter into their metabolism.

Many animals consume phytoplankton which serve not only as their food but also as a potential source of radioactivity to them. Davis et al. (2) state that all aquatic organisms which inhabit the Columbia River downstream from the Hanford reactors contain concentrations of radioisotopes, but algae contain the most kinds and the largest amounts of isotopes.

Seymour (14) has found that plankton organisms in general will concentrate radioisotopes from sea water by a factor of one to many thousands and appear to be the best biological indicators of the presence of radioisotopes in the sea. In fact, if one wishes to know if an aquatic environment has received fallout, a radiological analysis of a plankton sample taken from that environment will provide this information.

In the aquatic environment many factors operate to replenish nutrients utilized for phytoplankton growth. Simultaneously, other factors tend to reduce the standing crop of phytoplankton cells. This combination of conditions may result in a rapid division of cells without any large variation in the number composing the standing crop. Similar conditions have not held for investigations in the laboratory on the uptake and concentration of nutrients and radioactive isotopes. Here the classical technique of growing cultures in confined volumes of medium subjects cells to more drastic conditions. Generally, a culture medium initially contains high concentrations of nutrients (see figure 2). As the cells increase in number, the nutrient concentrations are reduced until some factor becomes limiting and cell division is stopped. It may be that the concentration of a nutrient is initially present in such high quantities that a reduced rate of division results. With this slower division rate, the nutrient eventually is reduced to a level at which cell division may become optimum under

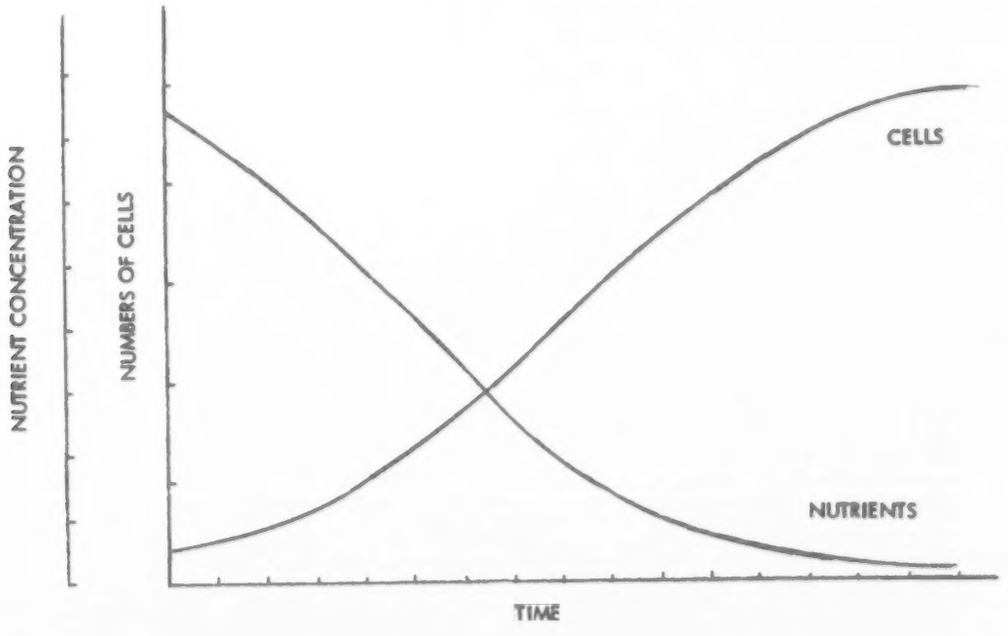


Figure 2.-Theoretical Curve Showing Growth of Population of Algal Cells and Their Removal of Nutrients from a Confined Volume of Medium

the conditions and continue at this rate until the nutrient is further reduced to a concentration at which it becomes limiting, reducing the rate of division or stopping it altogether.

It is now questionable whether data obtained by the classical culture technique are representative of the processes occurring in the aquatic environment. Culture experiments in a confined volume of medium are short term and during the course of the experiment the population will go through all phases of the growth curve. Since the cells change physiologically as the population passes through these phases, it follows that the biochemical mechanisms controlling the uptake of radioisotopes may also change during the experiment. As nutrients are consumed and excreted products accumulate, the environment obviously changes with an increase in numbers of cells. As an example of complications that can result, an increase in pH during photosynthesis may alter the solubility characteristics of the radioisotope being studied.

Williams and Swanson (17) and investigators at our laboratory have used the classical culture technique in following the accumulation of $Cs^{137}$ by phytoplankton. Williams and Swanson found that fresh water species concentrated $Cs^{137}$ from 52 to 1,530 times over its concentration in the medium. Our investigators (1) found that marine species concentrated $Cs^{137}$ not more than 3.1 times over levels in the medium. This difference in levels of concentration is due, no doubt, to the high concentration of potassium in sea water. Since the concentration factor represents the ratio of activity in a gram of organism in relation to that in a gram of water, a drastic reduction in the amount of activity in the water will obviously increase the concentration factor. In table 3 Williams gives the percentage of $Cs^{137}$ removed from the medium during certain periods of time. These tabulated data show that on the fourteenth day Euglena cells had concentrated $Cs^{137}$ about 706 times over amounts remaining in the medium. On that day, less than 18 percent of the original $Cs^{137}$ was still in the medium. Using similar conditions, we found that Nannochloris cells removed only 0.1 percent of the

Table 3.-Removal of Cesium-137 from Culture Medium by Euglena Cells (17)

| Days | Percentage $Cs^{137}$ removed |
|---|---|
| 6 | 69 |
| 11 | 82 |
| 14 | 706 (concentration factor) |
| 18 | 86 |
| 34 | 96 |

$Cs^{137}$. As is shown in figure 3, the uptake of $Cs^{137}$ closely followed the growth curve of the cells. Since there is such a small reduction in the availability of $Cs^{137}$ to Nannochloris, the concentration factor for Nannochloris cells should be representative of what occurs in the oceans.

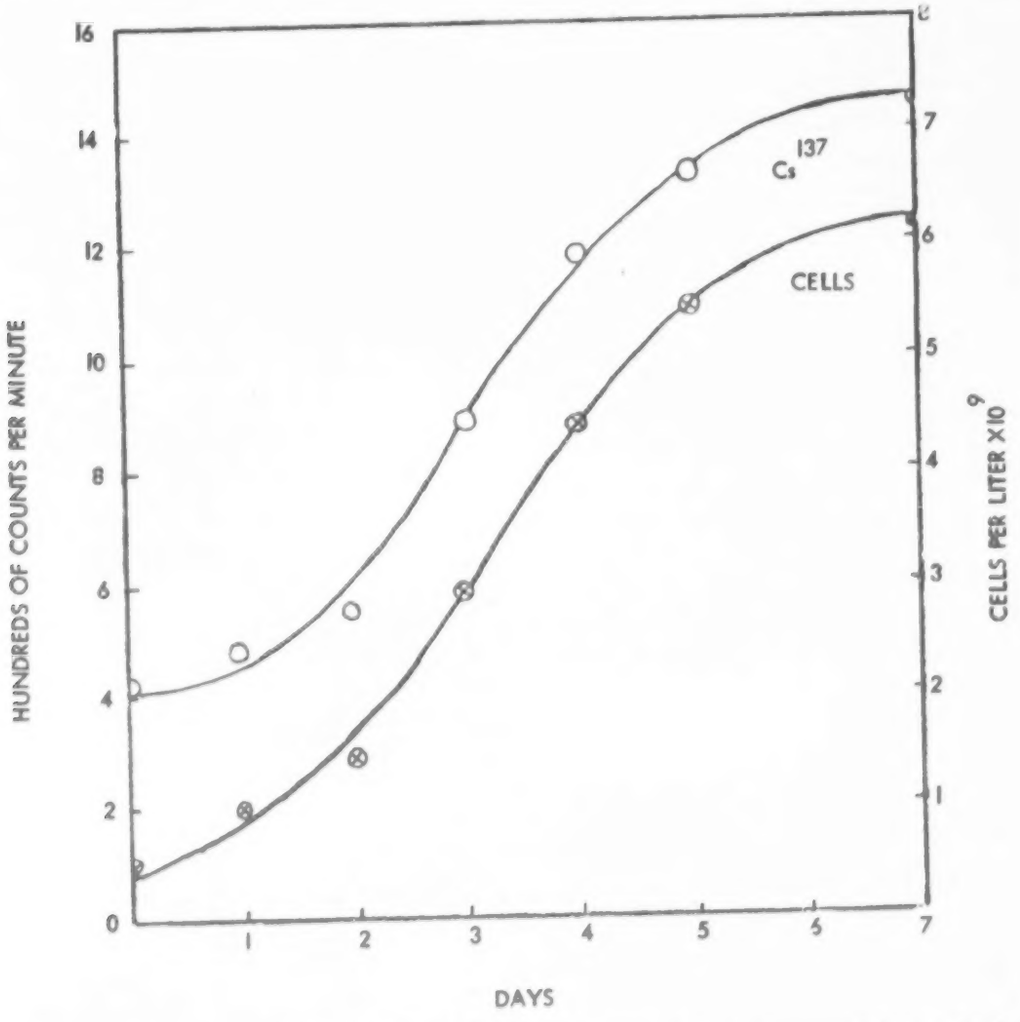


Figure 3.-Accumulation of $Cs^{137}$ by a Population of Nannochloris Cells

To grow algae in the laboratory under conditions that more nearly simulate growth in a natural environment, a continuous culture system has been devised. Bacteriologists have used a similar culture apparatus called a chemostat. Both Dr. Taylor (15) of the Chesapeake Bay Institute and the author with the assistance of Marianne B. Murdoch, are using such a system for growing algae. With this culture method it is possible to maintain a constant population of cells in the culture container and a desired level of nutrients in the water. This insures that cells will grow under more nearly constant conditions similar to those occurring in nature.

The main components of the continuous flow system (figure 4) are a reservoir of culture medium, a continuous infusion pump, a pyrex resin kettle or growth chamber, and a discharge system to remove medium and cells at the same rate that new medium is pumped into the growth chamber. Cells are grown in the resin kettle which will hold 2,650 ml of medium and are kept uniformly dispersed by means of a Teflon magnetic stirrer. Inflowing medium is pumped from the reservoir to the growth chamber by the infusion pump. Flow rates can be controlled by selecting one of the 12 mechanical speed controls on the pump or by selecting any one of 5 different size syringes which can be adapted to the pump. These combinations give a choice of 60 flow rates ranging from 0.001 to 38 ml per minute. The population of cells can be stabilized at a given level by maintaining the flow of medium at a rate which will remove cells as rapidly as they are formed or by varying a limiting factor in proportion to flow rate so that an excess of cells will not accumulate. The flow system is kept in a constant temperature room with a temperature of $20^{\circ} \pm 2^{\circ}$ C. Cells are grown in constant illumination provided by daylight fluorescent lamps.

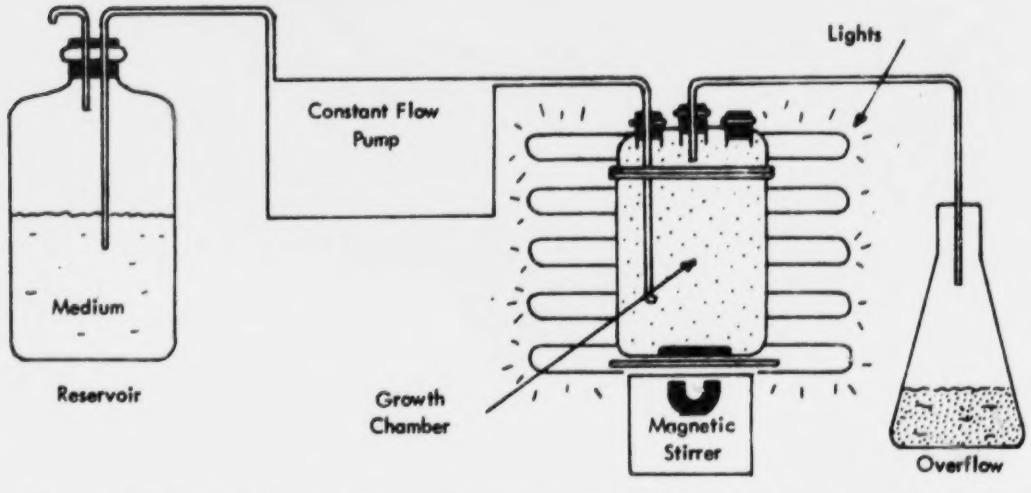


**Figure 4.-A Continuous Flow System for Culturing Algae in a Controlled Concentration of Nutrients**

The concentration of $P^{32}$ from the medium by Dunaliella cells was followed at three different rates of flow. The medium contained 18 microgram atoms phosphorus per liter ($\mu$gAP/l) and all other conditions except flow rate were similar for the three experiments. After 3 days in the growth chamber, cells were filtered from the medium and a concen-

tration factor was determined for the cells (table 4). As the flow rate was increased, the concentration factor increased.

Table 4.-Effect of Flow Rate on the Concentration of Phosphorus-32 by Dunaliella Cells

| Flow rate ml/day | Concentration factor |
|---|---|
| 300 | 554 |
| 700 | 677 |
| 1400 | 934 |

The influence of the amount of phosphorus in sea water on the level to which it is concentrated by Dunaliella was followed since phosphorus is frequently the limiting nutrient in the oceans. Phosphorus was used in concentrations of 1, 6, and 60 μgAP/1.

Dunaliella cells were grown in medium containing no added phosphorus until cell division ceased. Any further division by these cells would require additional phosphorus from the medium. Sufficient cells to give a population size of $26 \times 10^7$ cells per liter were added to the growth chamber. Immediately before starting the inflow of new medium containing 1 μgAP/1, 5 microcuries of radioactive phosphorus were added to the growth chamber and to the inflowing medium. A pumping rate of 1,200 ml per day was maintained for the 4 days during which time numbers of cells and concentrations of both $P^{32}$ and nonactive inorganic phosphorus in the medium were followed. At the end of this time cells were filtered out of the medium, weighed, and their contained $P^{32}$ measured. By comparing the $P^{32}$ in a unit-weight of algae with that in the medium, a concentration factor was calculated. This procedure was repeated, using 6 μgAP/1 and again with 60 μgAP/1. In table 5 it can be seen that the higher the level of phosphorus in the medium, the lower the concentration factor.

Table 5.-Concentration of Phosphorus-32 by Dunaliella Cells when Grown in Medium Containing Different Levels of Stable Phosphorus

| Phosphorus (μgAP/l) | Concentration factor |
|---|---|
| 1 | 3,900 |
| 6 | 1,943 |
| 60 | 74 |

The concentration of $Zn^{65}$ by Dunaliella cells was also determined with all other conditions in the flow system similar except for the level of zinc in the culture medium (table 6). The cells grew in the growth chamber for 6 days before they

were filtered from the medium and their concentration factors determined. As the zinc concentration in the medium was increased the concentration factor decreased.

Table 6.--Concentration of Zinc-65 by Dunaliella Cells when Grown in Medium with Different Levels of Stable Zinc

| Zinc (μg) | Concentration factor |
|---|---|
| 15 | 16,900 |
| 1500 | 11,500 |
| 3000 | 3,800 |

Dunaliella cells were also grown for 3 days in the flow system containing medium flowing at the rate of 700 ml per day and dosed with $Cs^{137}$. The cells were found to have concentrated radioactive cesium 12.6 times over the level in the medium.

Carteria cells were grown in the flow system which was set for a flow rate of 1,000 ml per day. After growing for 6 days in medium containing $Sr^{85}$, the cells were filtered from the medium and a concentration factor was determined. It was found the Carteria cells concentrated radioactive strontium 16.4 times over the level in the medium.

Mollusks are filter feeding animals and will concentrate in their digestive tracts or bodies any radionuclide occurring in or on phytoplankton. Thus, phytoplankton are an important step in the transmission of radioactive elements through certain food webs. The rate of accumulation, level of concentration, mode of entry, and assimilation of specific radionuclides by mollusks will depend largely on the physical state of the nuclides in the water and on the physiological demand of the mollusks for the element. Elements and their radioisotopes are present in sea water as particles and ions. A particulate radionuclide will become associated with molluskan shellfish by adsorption to the shellfish's body surfaces; if ingested, the radionuclide will pass through the digestive tract with only a small amount being assimilated. Ionic radionuclides readily pass through tissue membranes and are, therefore, assimilated to higher levels.

The giant "killer" clam of the tropic Pacific, Tridacina, concentrates $Co^{57, 58, 60}$ and $Mn^{54}$ in its kidney, or hepatopancreas (8, 16). Radioactive cobalt, manganese, and zinc are concentrated by the tropical horse clam, Hippopus. Stable zinc is present in the Hippopus kidney at a level 17 times as high as that in the Tridacina kidney. Also $Ru^{106}$-$Rh^{106}$ and

$Zr^{95}$-$Nb^{95}$ are concentrated in the visceral mass of these clams.

Experiments conducted by Thomas J. Price of our laboratory have shown that $Sr^{89}$ is not concentrated in the soft tissues of oysters and clams over the $Sr^{89}$ levels found in the ambient water; however, the shells do concentrate $Sr^{89}$ about 10 times over amounts in the water. Oysters, clams, and scallops were found to take up $Cs^{137}$ over its concentrations present in the sea water. In a comparative experiment lasting for 20 days, oysters accumulated $Cs^{137}$ 5 times over this nuclide's concentration in the sea water, while clams had an accumulation factor of 6. By the tenth day, the adductor muscles of scallops concentrated $Cs^{137}$ 10 times more than the level in the water and continued thereafter to take up more $Cs^{137}$. The visceral mass of the scallop had accumulated the radionuclide only 8 times.

The blue crab is an omnivorous predator and scavenger and during its planktonic larval stages feeds on the zooplankton and possibly phytoplankton. Thus, it is involved in many of the trophic levels. Pollutant radionuclides which are accumulated by virtually any of the estuarial plants and animals will probably find their way into the tissues of the crab because of the great variety of plant and animal material, both living and dead, which the crab consumes. Moreover, since it seems to be beyond the powers of invertebrates to develop impermeable membranes, radionuclides present in the water are expected to accumulate in the tissues of crabs. There is a constant movement of water and ions between the crab and its ambient water, and it has been shown that even the crab's heavy carapace is permeable to water and salts (8), although, as is the case with virtually all living membranes, it is more permeable to water than to salts.

In experiments carried out by George H. Rees of our laboratory, it was found that $Sr^{85}$ is concentrated in the exoskeletons of crabs 25 to 50 times over its concentration in the water. This radioactivity is lost, together with the old exoskeleton, when molting occurs. Strontium-85 is not concentrated in the soft tissues over its concentration in the water.

Zinc-65 is taken up rapidly from the water and accumulates in all the tissues of blue crabs. The largest concentration of this isotope is reached in the hepatopancreas followed by gonad and muscle. After 29 days in sea water containing $Zn^{65}$, blue crabs had reached a whole body concentration of 33 times the concentration of this nuclide in the water.

Cerium-144 administered orally to blue crabs is excreted rapidly with very little being assimilated from the digestive tract. Twenty-four hours after administration, less than 4 percent of the original dose remained in the animals, most of this in structures associated with the alimentary canal. Radiocerium present in the water is accumulated in all the tissues of the crabs, apparently as the result of passage through the gill membranes into the blood. The gills themselves, by adsorption to their surfaces, take up $Ce^{144}$ and concentrate this isotope several hundred times greater than its concentration in the water.

Radioisotopic concentrations of different tissues have been determined for adult fish f om the Columbia River. Radioactive phosphorus was the dominant radioisotope, but significant concentrations of $Zn^{65}$ were found to occur in all tissues (2). Zinc-65 in the retina and iris of the eye was 3 or more times greater than in any other tissue. Other radioisotopes occurring in fish tissues were $Na^{24}$, $Sc^{46}$, $Cr^{51}$, $Mn^{54}$, $Fe^{59}$, $Co^{60}$, $Cu^{64}$, $Zn^{65}$, $Cs^{137}$, $Sr^{89}$, and $Sr^{90}$.

Donald E. Hoss of our laboratory has found that fish may accumulate more radioactivity from food than from water. During an experiment followed for 92 days, more $Zn^{65}$ was accumulated by postlarval flounder from food than from $Zn^{65}$-dosed water, even though the fish in the dosed water had 10 times as much of the isotope available to them. At the end of the 92-day period, the flounder continued to accumulate $Zn^{65}$ at a faster rate from food than they did from water. Growth data indicated that for the two different experiments fish were growing at the same rate. The accumulation of $Zn^{65}$ was found to be rapid in the digestive tract, liver, kidneys, and gill filaments, while in bone and muscle it was slower.

Fish accumulate radioactive materials by adsorption to their surface areas, absorption from the surrounding medium, or by ingestion. In nature these three modes of uptake can occur simultaneously, singly, or in various combinations depending on the water, the food habits of the fish, the length of time an area has been radioactively polluted, or the length of time the fish remain in the polluted area.

Only a few fission products were found in the reef and lagoon fishes of the Pacific test area, but induced radioisotopes were present. Ranked in order of abundance, these were: $Fe^{55, 59}$, $Zn^{65}$, $Co^{57, 58, 60}$, and $Mn^{54}$ (14). Oceanic fishes differed from reef and lagoon fishes in that $Zn^{65}$ ranked

first in oceanic fishes. Tuna collected in the open sea near the test site contained $Zn^{65}$ and $Fe^{55}$. The greatest concentration of radioisotopes in the tuna was found in the alimentary tract. For the different tissues, the descending order of uptake was liver, skin, bone, and muscle. Strontium was taken up from the water by fishes and concentrated to the highest levels in bone and scales. It has been reported that a discrimination of from 3 to 10 against strontium in favor of calcium occurred in most fishes. Rare earth radionuclides were concentrated chiefly in the internal organs, while $Cs^{137}$ was concentrated to the greatest extent in the muscle tissue.

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# RESEARCH STUDIES ON THE CLINCH RIVER AND MOHAWK RIVER

by

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The activities which are performed by the Cooperative Studies Unit at the Robert A. Taft Sanitary Engineering Center in Cincinnati are confined to the fresh water environment and do not include the marine environment. One such activity is the radiological study of the Clinch and Tennessee Rivers. As shown by figure 1, the sampling sites for this study are located on the two rivers in those areas which were and still are affected by the nuclear operations of the Oak Ridge National Laboratory. The Clinch River flows into the Tennessee River, which in turn joins the Ohio River at Paducah, Kentucky. The first sampling site, Station 1, is located on the Clinch River at Norris Dam, far upstream from the Oak Ridge operations in order to provide baseline control samples, that is, samples having their radiation levels uninfluenced by the radioactive wastes discharged from the Oak Ridge installation. Station 2 is located on White Oak Creek, a small stream which enters the Clinch River at Clinch River Mile (CRM) 20.8 and which contains the major portion of the radioactive wastes discharged by the Oak Ridge facility. Station 3 is located on the Clinch River about 6 miles below the mouth of White Oak Creek; Station 4, at Kingston, Tennessee, is located about 16 miles below White Oak Creek. Station 5, a control station, is on the Tennessee River at Fort Loudoun Dam. Station 6 is located at Watts Bar Dam about 60 miles below the mouth of White Oak Creek, and Station 7, near Chattanooga, is about 125 miles downstream from White Oak Creek and in the vicinity of Chickamauga Dam. The area of study thus extends over a range of about 185 miles of stream flow, that is, from Norris Dam to Chickamauga Dam.

The samples collected for this study included those of sediment, water, and organisms such as algae, plankton, clams, snails, fish, and aquatic vascular plants. These samples were sent to Public Health Service radiological laboratories in Cincinnati to be analyzed for specific radionuclides. Figure 2 is a gamma spectrum of an 8-day composite of White

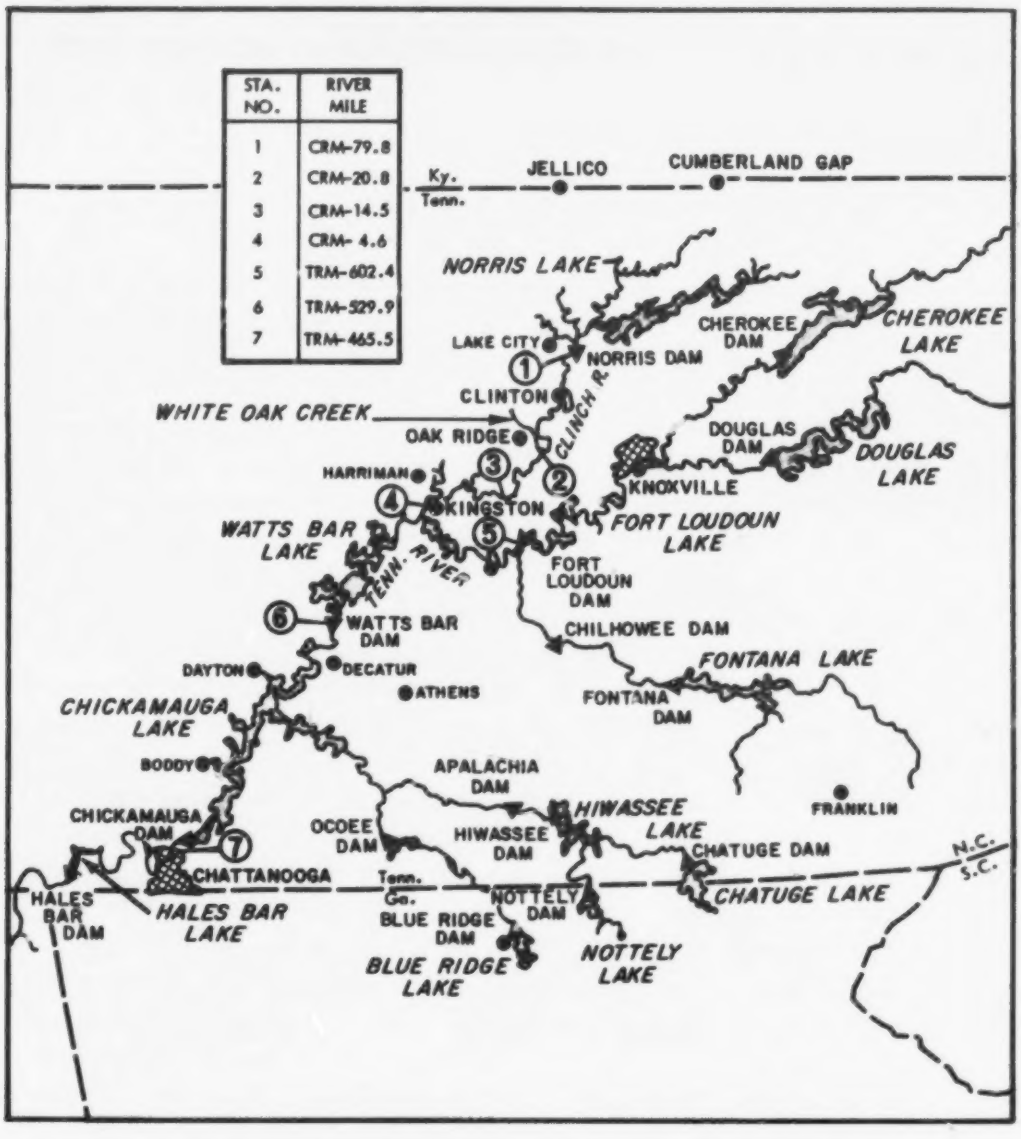


**Figure 1.-Location of Sampling Stations on the Clinch and Tennessee Rivers**

Oak Creek water. This composite was a sample of the actual effluent entering the Clinch River and contained the gamma-emitting radionuclides $Ce^{144}$, $Ru^{106}$, $Cs^{137}$, and $Co^{60}$. The data, shown in table 1, seem to indicate that $Ce^{144}$ had disappeared from the water phase after about 6 miles of stream flow, and that $Cs^{137}$ had disappeared after about 16 miles of flow, with cobalt having been reduced to only trace levels. In figure 3, the activities of the radionuclides are plotted against stream distances in miles.

After studying this latter plot, one would naturally question the lower levels of activities found in the water at Station 6

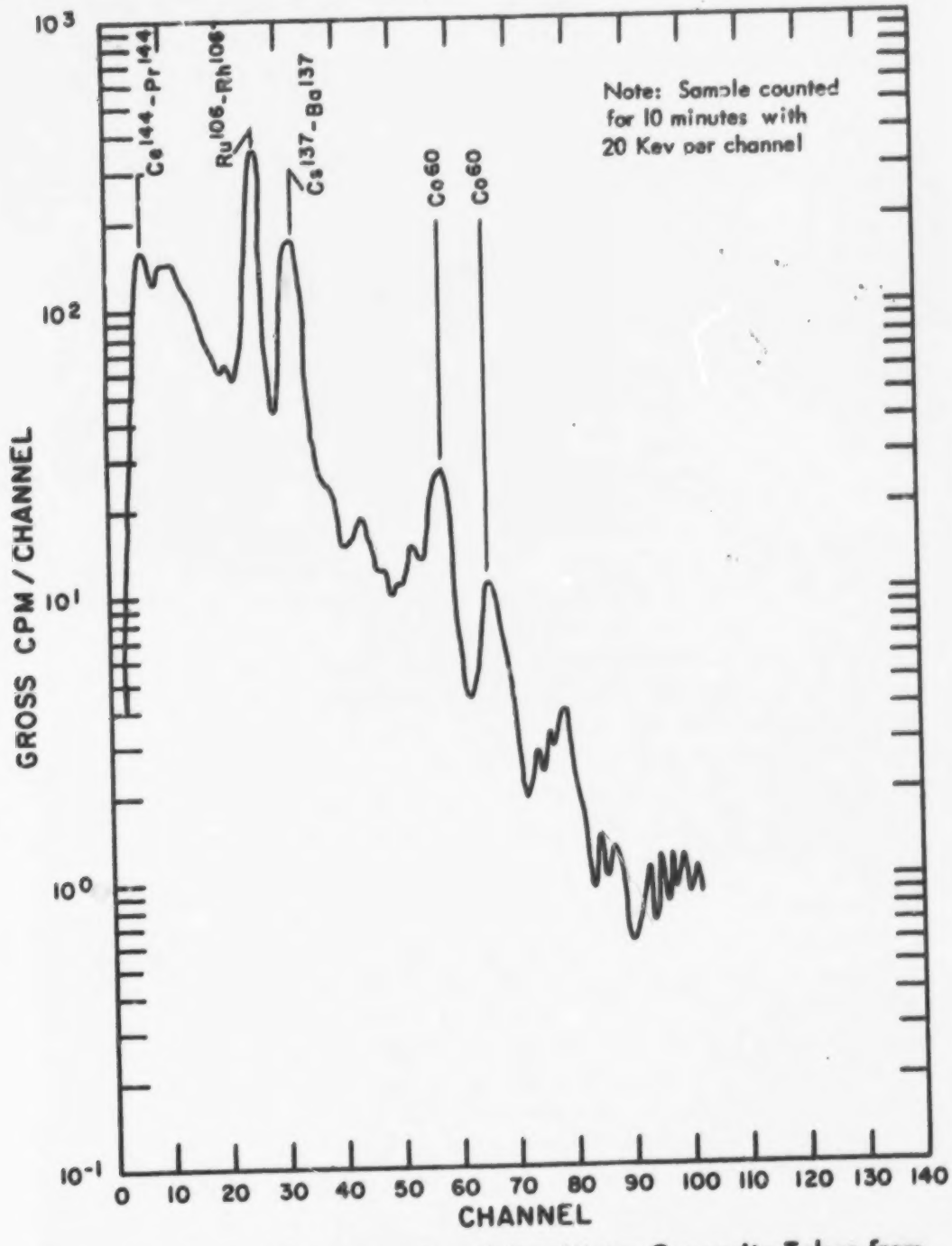


**Figure 2.-Gamma Spectrum of an 8-Day Water Composite Taken from White Oak Creek**

(Watts Bar Dam) as compared to those found at Station 7 (near Chattanooga). In discussing these lower levels of activity with Mr. Milo Churchill of Tennessee Valley Authority, it was learned that the Clinch River water isgenerally much colder than the other water found in Watts Bar Reservoir; consequently, one would expect that the radioactive wastes borne by the Clinch

Table 1.-Radionuclide Concentrations in Water at Various Stations on Clinch and Tennessee Rivers February 9-15, 1960 (Concentrations in pc/l)

| Station | $Ce^{144}$-$Pr^{144}$ | $Ru^{106}$-$Rh^{106}$ | $Cs^{137}$-$Ba^{137}$ | $Zr^{95}$-$Nb^{95}$ | $Zn^{65}$ | $Co^{60}$ | $Sr^{90}$ * |
|---|---|---|---|---|---|---|---|
| 1 (CRM 79.8) | - ** | - | - | - | - | - | 0.5 |
| 2 (CRM 20.8) | 985 | 14,300 | 2150 | T | - | 321 | 2825 |
| 3 (CRM 14.5) | 625 | 940 | 270 | - | - | 17 | 19.7 |
| 4 (CRM 4.6) | - | 860 | 27 | T | - | T | 5.8 |
| 5 (TRM 602.4) | - | - | - | - | - | - | 0.4 |
| 6 (TRM 529.9) | - | 86 | - | T | - | T | 1.5 |
| 7 (Raw) (TRM 465.5) | - | 250 | - | - | T | T | 4.4 |
| 7 (Treated) (TRM 465.5) | - | 170 | - | - | - | T | 3.6 |

* $Sr^{90}$ values shown only for samples analyzed. Values obtained by radiochemical analyses.
** - indicates levels below detectability. T indicates trace.

River would be carried to the bottom of the reservoir by the colder water. Since the water sample had been taken from the surface layer at Station 6, the sample so collected in all probability did not represent Clinch River water but possibly a stagnant water bearing very little radioactive wastes. The water collected at Station 7 was a more representative sample, since this water was well mixed in its passage through the turbines at Watts Bar Dam; this accounts for the rise in radioactivity at this station.

The next two figures, 4 and 5, show gamma spectra of fish samples. Figure 4 is a gamma spectrum of a whole gizzard shad, a fish which had been taken from White Oak Creek. Gizzard shad, being plankton feeders, do not eat fish. It may be assumed then that the relatively high concentrations of ruthenium, cesium, and cobalt found in the shad result from their feeding habits, i.e., these radionuclides are taken up by the plankton which in turn are taken up by the shad. Figure 5 is a gamma spectrum of the flesh of a carp which had been collected from the Clinch River at Kingston, Tennessee. The only radionuclides of prominence indicated in this spectrum are $Cs^{137}$ and $K^{40}$. There are two possible explanations which could probably account for the high level of cesium in the flesh. The first explanation considers the fact that cesium is chemically similar to potassium; therefore, one might expect that these nuclides have similar metabolic pathways. Potassium is a bulk element in animal flesh, and if cesium were present in a stream, some of this cesium could be incorporated in fish flesh along with potassium. The second

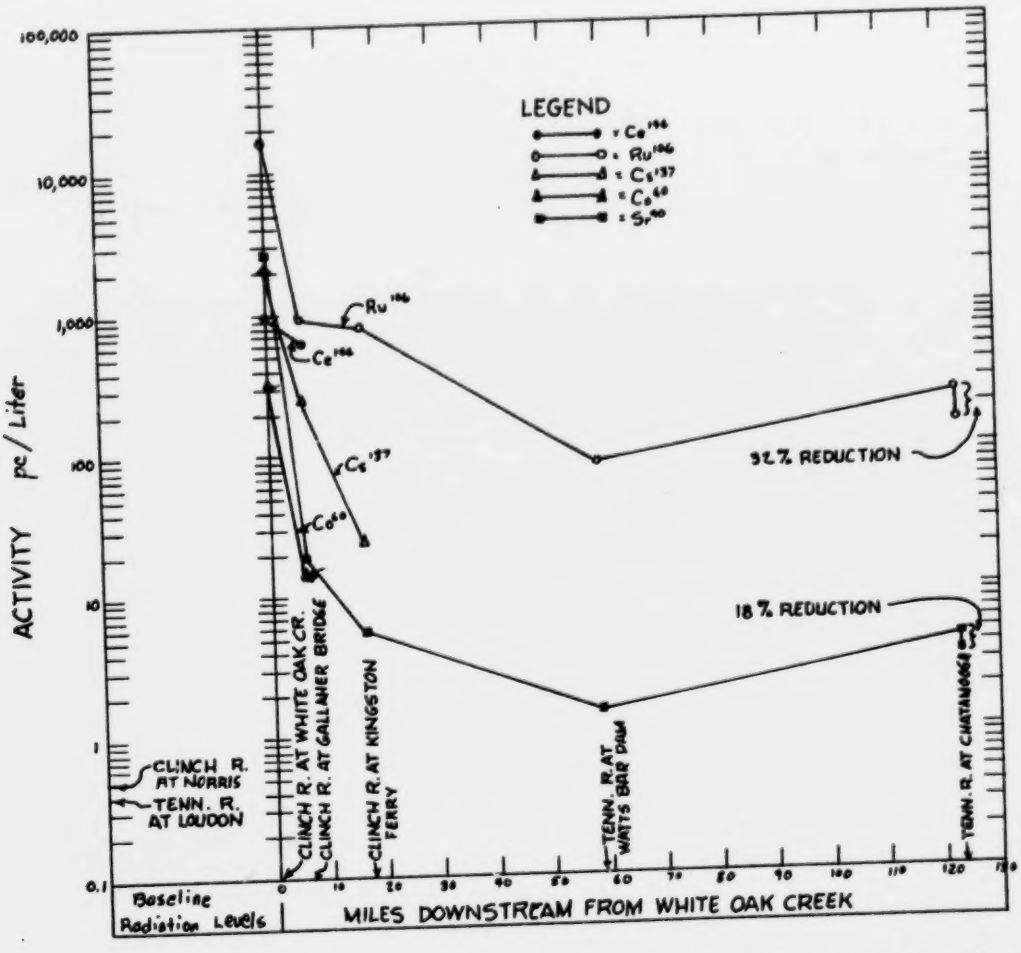


**Figure 3.-Radionuclide Concentration in Waters Sampled from the Clinch and Tennessee Rivers**

explanation is based on the fact that carp are bottom feeding fish; that is, they strain their food from the bottom sediments by means of gill rakers. As will be shown later, cesium is concentrated to a high degree by the sediments of the Clinch River, and consequently the intestinal content of these filter-feeding fish could be high in cesium as a result of ingesting bottom sediments.

Figure 6 shows a gamma spectrum of the nuclides contained in a bottom sediment sample collected at the mouth of White Oak Creek. The nuclides $Ce^{144}$, $Ru^{106}$, $Cs^{137}$, $Zr^{95}$ $Nb^{95}$, and $Co^{60}$ were found to be concentrated to a greater extent in this sediment than in the water taken from the same location. Figure 7 is a spectrum of a Clinch River sediment sample collected at Station 4, which is 16 miles downstream from the mouth of White Oak Creek. It will be noted that the nuclides present at Station 4, although in lower concentrations, are of the same kind as those found at the mouth of White

Oak Creek. Table 2 shows, in picocuries (pc) per kilogram of dry weight, the concentrations for the radionuclides found in bottom sediment samples collected from the Clinch and Tennessee Rivers. It will be noted that the data given in the first two rows of this table are for baseline samples collected at Fort Loudoun and Norris Reservoirs, respectively. The data show a relatively sharp increase in activities from

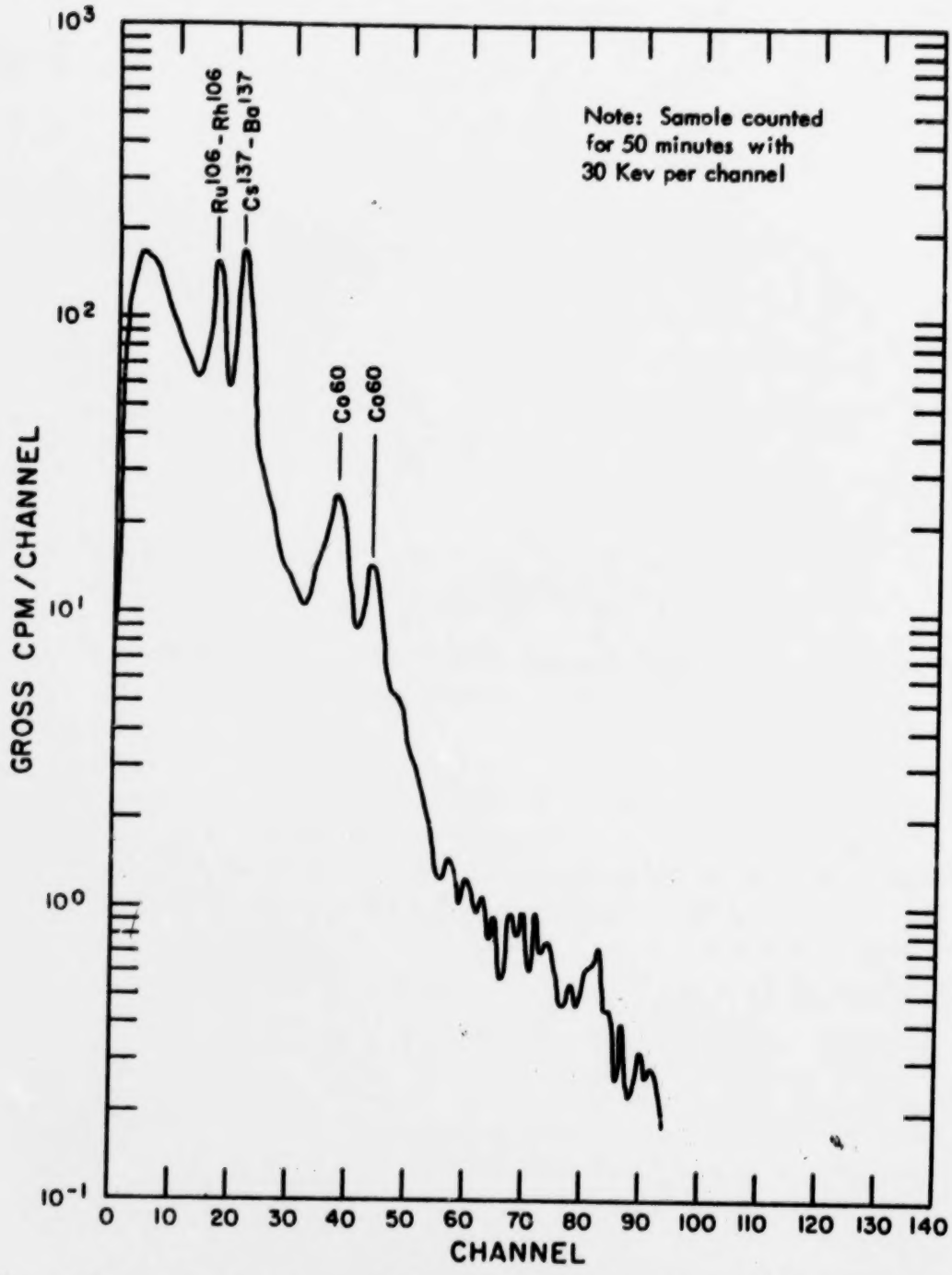


Figure 4.-Gamma Spectrum of Gizzard Shad Taken from White Oak Creek

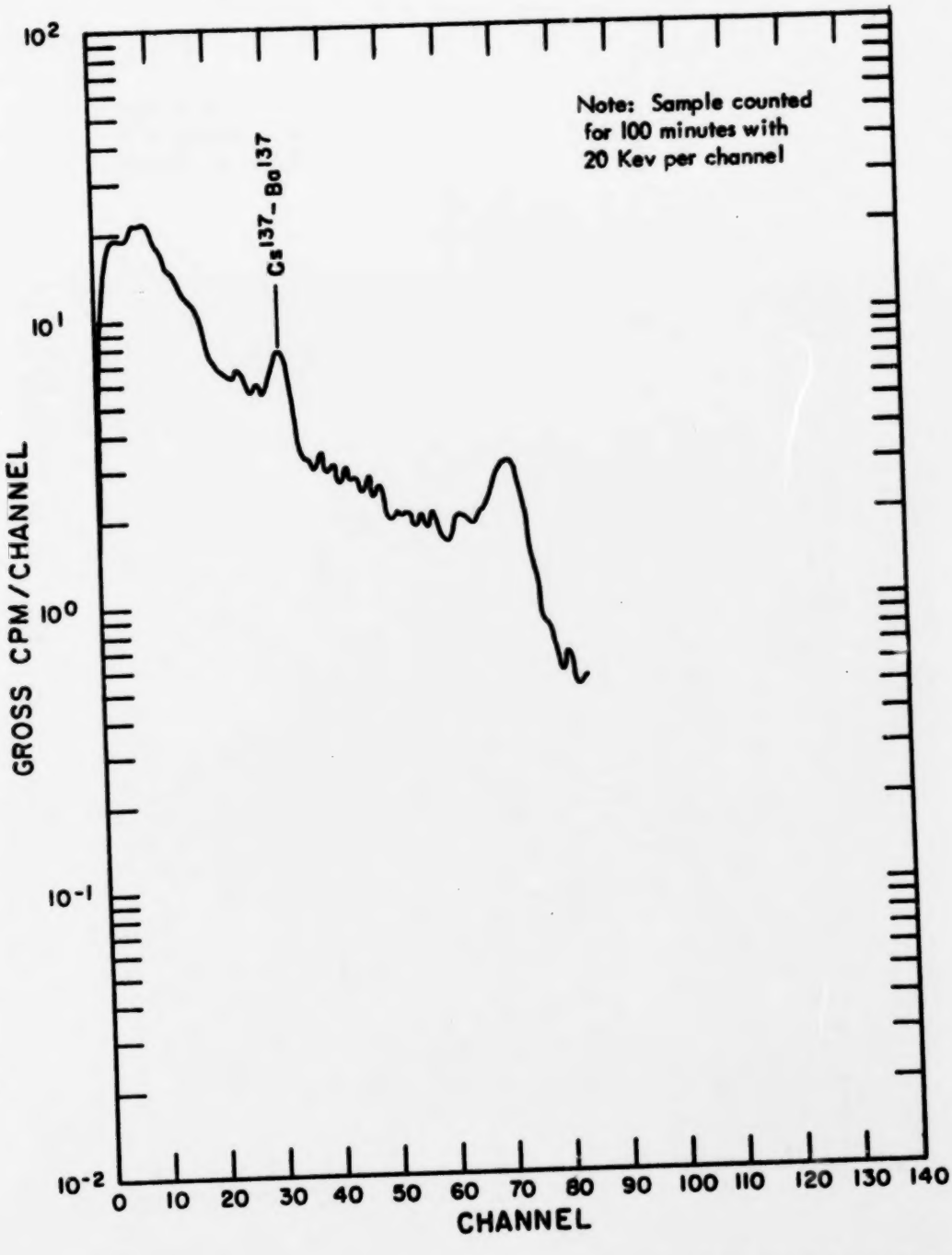


**Figure 5.-Gamma Spectrum of the Flesh of a Carp Which Had Been Taken from the Clinch River at Kingston, Tennessee**

row 2 downward, indicating that the nuclear operations at Oak Ridge contributed to much of the activities found in the Clinch River sediments. These activities, as shown in figure 8, are plotted against the distances at which the sediment samples were collected. Again, the values at Station 6 are lower than

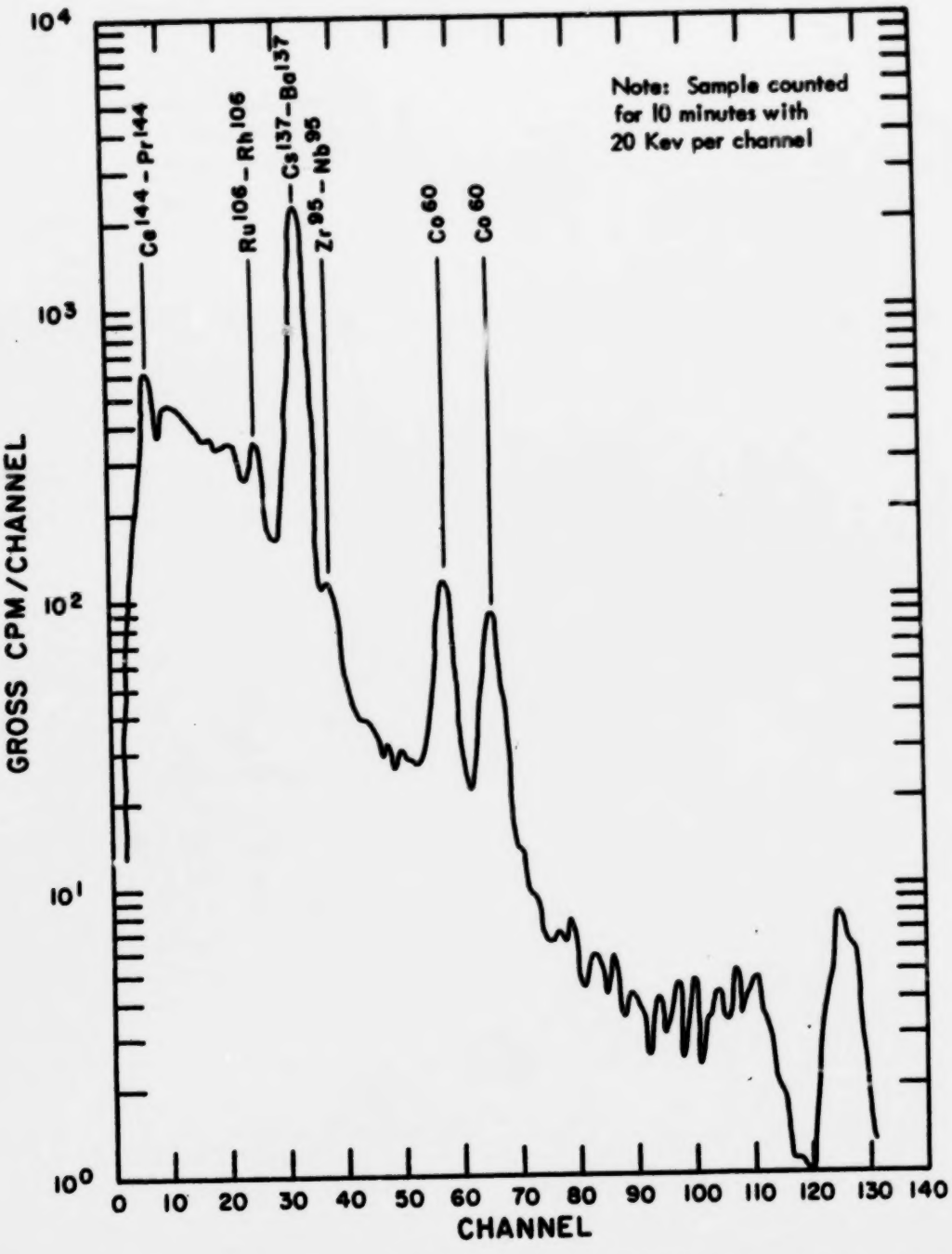


**Figure 6.-Gamma Spectrum of Bottom Sediment Collected from the Mouth of White Oak Creek**

those at Station 7. Unlike the similar situation discussed previously, the explanation for these data is somewhat easier. The sample collected at Station 6 was taken from below Watts Bar Dam. The water velocity at this point was quite high; consequently, the sediment so collected was almost pure quartz sand with little evidence of silt. The sediment sample

collected at Station 7, however, was collected at the face of the dam and represented silt deposited in the backwater above the dam. Quartz is impervious, has a low inherent charge and a low ion exchange capacity. The silt, however, is more finely divided than quartz sand and is composed mostly of illitic and vermiculitic clays which have relatively high ion exchange capacities. Therefore, greater amounts of radioactivity can be associated with silt than with quartz sand.

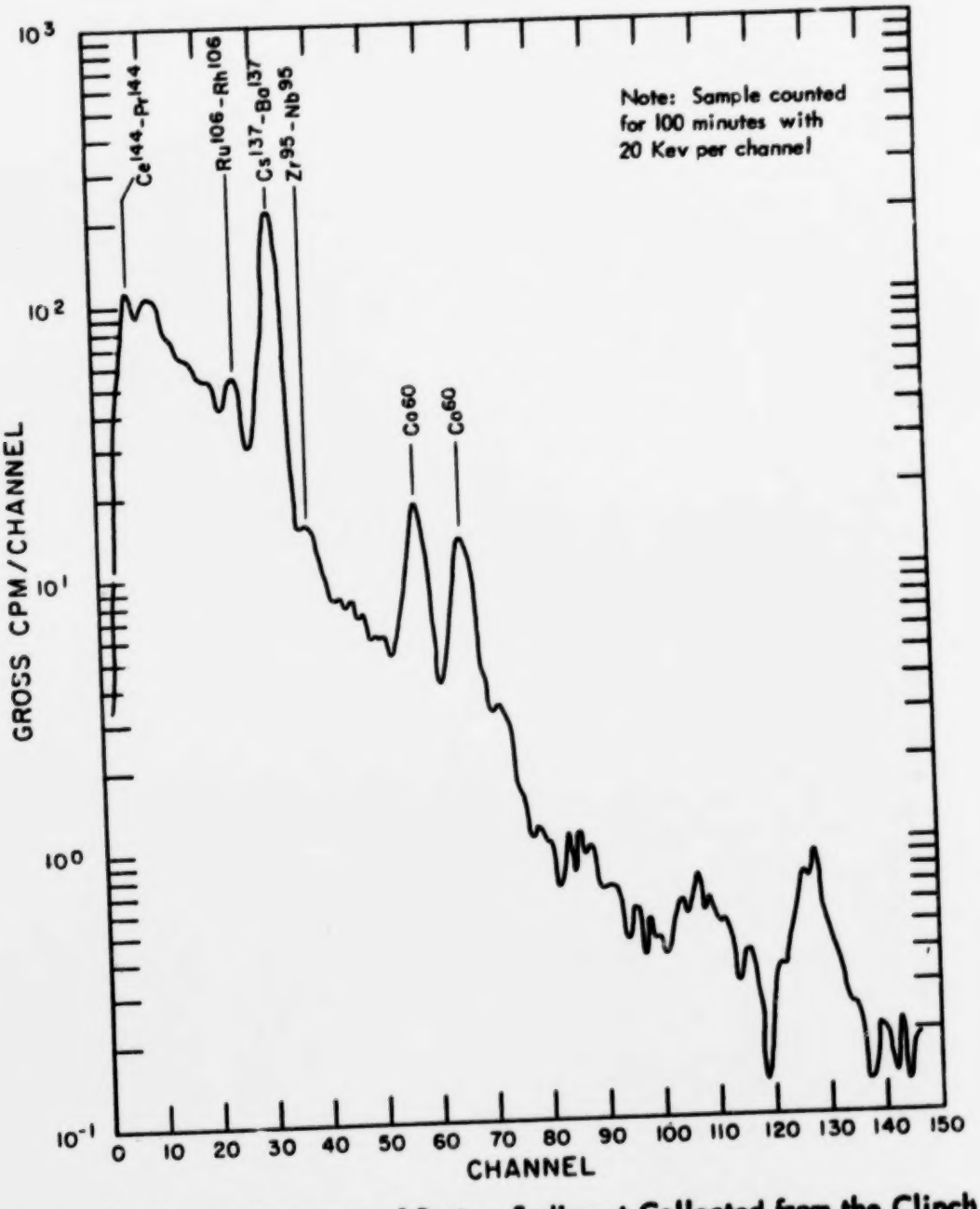


**Figure 7.–Gamma Spectrum of Bottom Sediment Collected from the Clinch River at Kingston, Tennessee**

Table 2.-Radionuclide Concentrations Found in Bottom Mud Samples Collected from the Clinch and Tennessee Rivers February 9–15, 1960
(Concentrations in pc/kg dry weight)

| Sample location | $Ce^{144}$-$Pr^{144}$ | $Ru^{106}$-$Rh^{106}$ | $Cs^{137}$-$Ba^{137m}$ | $Zr^{95}$-$Nb^{95}$ | $Zn^{65}$ | $Co^{60}$ | $Sr^{90}$* |
|---|---|---|---|---|---|---|---|
| Ft. Loudoun Reservoir | $1.58 \times 10^3$ | - ** | T | 105 | - | - | 283 |
| Norris Dam Reservoir | $1.17 \times 10^3$ | 626 | T | 104 | - | - | 74 |
| Clinch River at mouth of White Oak Creek | $2.32 \times 10^6$ | $2.44 \times 10^6$ | $8.75 \times 10^6$ | $7.6 \times 10^4$ | - | $5.1 \times 10^5$ | $9.7 \times 10^4$ |
| Clinch River 150' below mouth of White Oak Creek | $5.7 \times 10^4$ | $1.0 \times 10^5$ | $3.64 \times 10^5$ | $4.12 \times 10^3$ | - | $2.1 \times 10^4$ | $8.6 \times 10^3$ |
| Clinch River 300' above Gallaher Bridge | $2.75 \times 10^6$ | $3.98 \times 10^6$ | $3.16 \times 10^5$ | $2.36 \times 10^5$ | - | $2.5 \times 10^5$ | $5.0 \times 10^3$ |
| Clinch River 1200' above Anderson Ferry | $2.22 \times 10^4$ | $7.5 \times 10^4$ | $10.15 \times 10^4$ | $1.75 \times 10^3$ | - | 898 | 260 |
| Clinch River at mouth of Emory River | $2.37 \times 10^3$ | $7.97 \times 10^3$ | $1.21 \times 10^4$ | T | - | 771 | 900 |
| Tennessee River below Watts Bar Dam | - | T | 803 | T | - | - | 170 |
| Tennessee River at face of Chickamauga Dam | 3442 | 5969 | 6884 | 298 | - | 887 | 535 |

* $Sr^{90}$ values shown only for samples analyzed. Values obtained by radiochemical analyses.
** - indicates levels below detectability. T indicates trace.

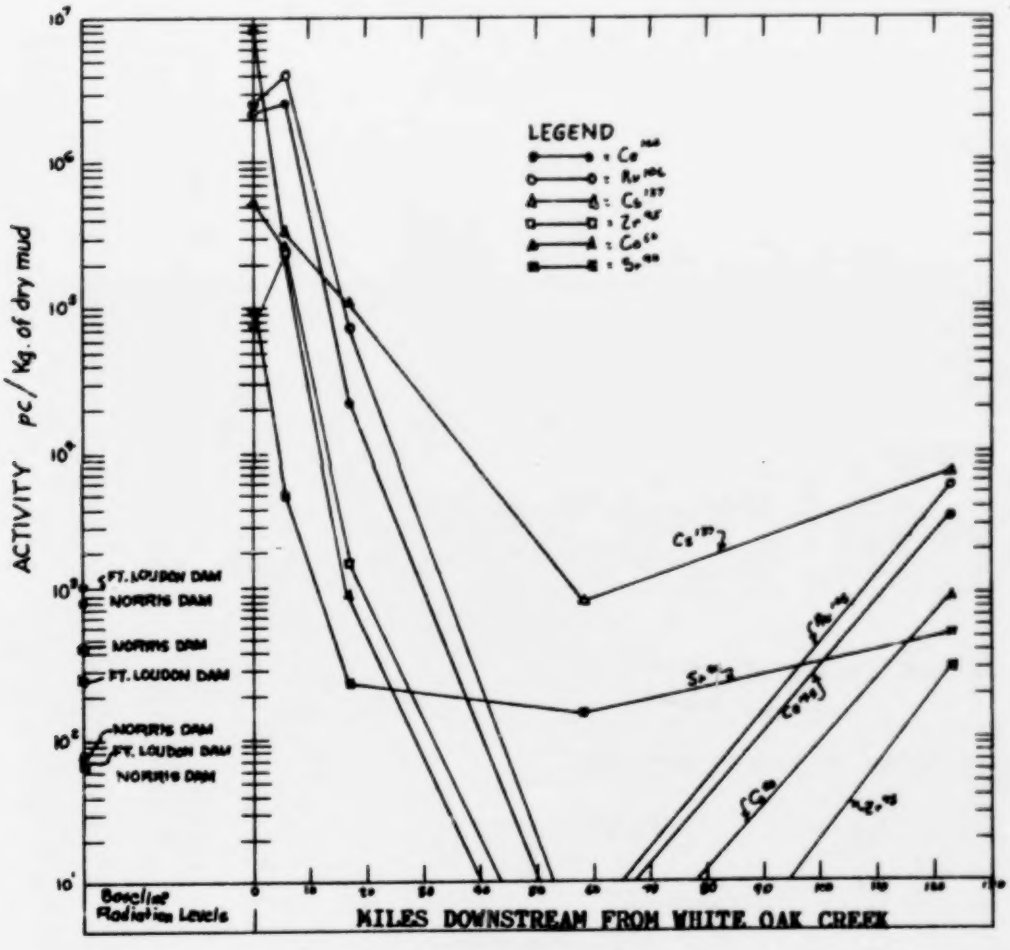


**Figure 8.-Radionuclide Concentrations in Bottom Sediments Collected from the Clinch and Tennessee Rivers**

Cross-sectional samples of bottom sediments were taken at six TVA silt ranges. The radiological data derived from these sediment samples were plotted in a cross-section type graph. Figure 9 shows such graphs in which each cross-section plot represents the levels of activity of a particular radionuclide contained in the samples collected at each tenth point across the stream at the particular range. The column to the extreme left of these plots, being the first column, shows a physical cross section of the river, while columns 2, 3, 4, 5, 6, and 7 respectively show the activity distribution of the nuclides $Ce^{144}$, $Ru^{106}$, $Cs^{137}$, $Zr^{95}$-$Nb^{95}$, $Co^{60}$, and $Sr^{90}$ as their concentrations vary in the bottom sediments found along the cross section. The vertical scales in these activity plots are not necessarily the same, so in order to compare activities one against the other the smaller plots on the right hand side of cross-sectional plots have been made to a constant scale.

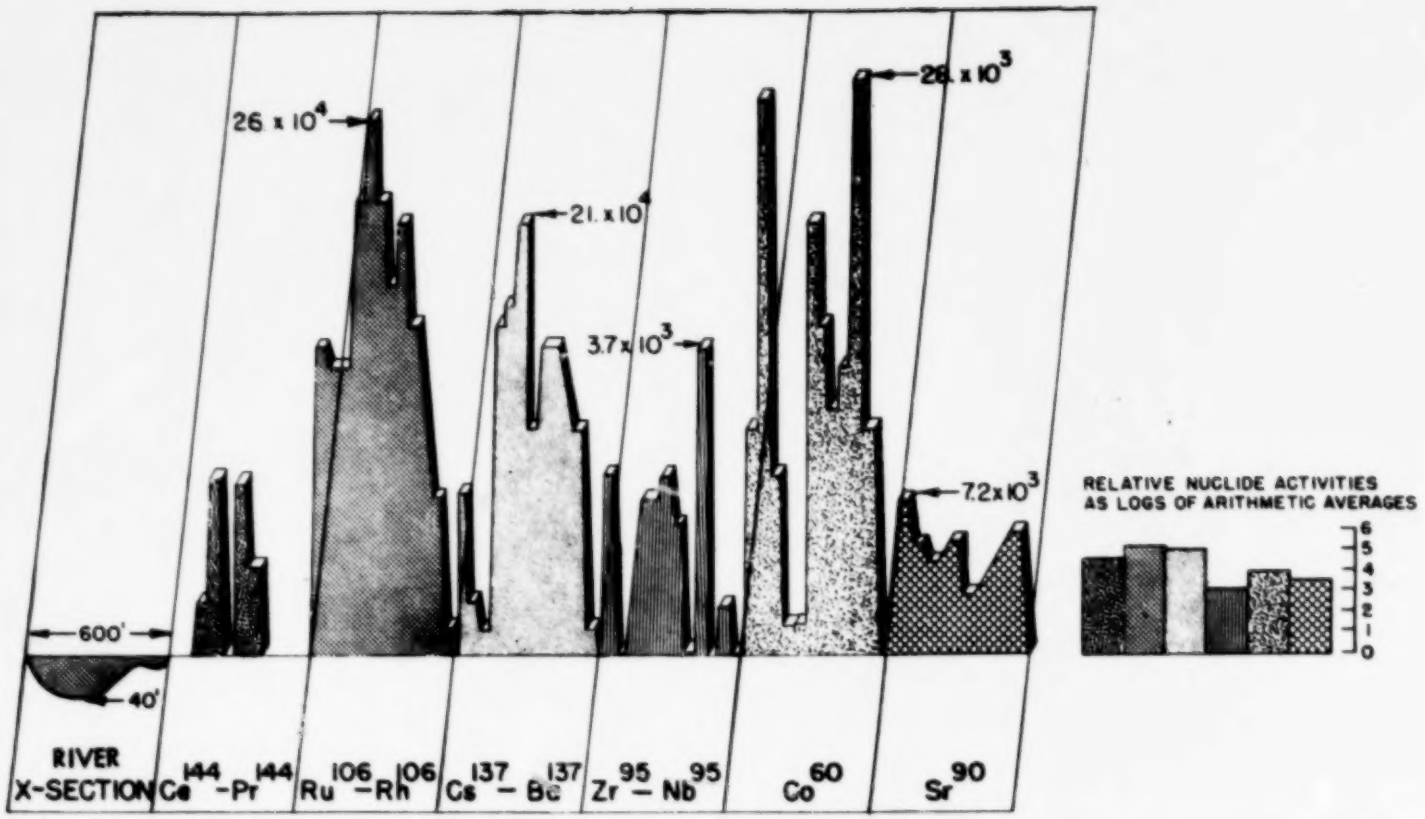


**Figure 9.-Cross Sections Representing the Concentrations of Certain Radionuclides Found in the Bottom Sediments Sampled from the Clinch River at River Mile 11.0**

**(NOTE: Vertical scale (pc/kg of dry sediment) of the concentration values is necessarily not the same for each of the concentrations.)**

Figure 9 displays the data for the cross section taken at CRM 11, 8 miles below the mouth of White Oak Creek. Figure 10 shows the data for the cross sections at CRM 5.4 and 4.1, respectively, about 15 and 16 miles below White Oak Creek. It will be noted from these data that the corresponding activity levels of the two stations are about the same on a per kilogram basis.

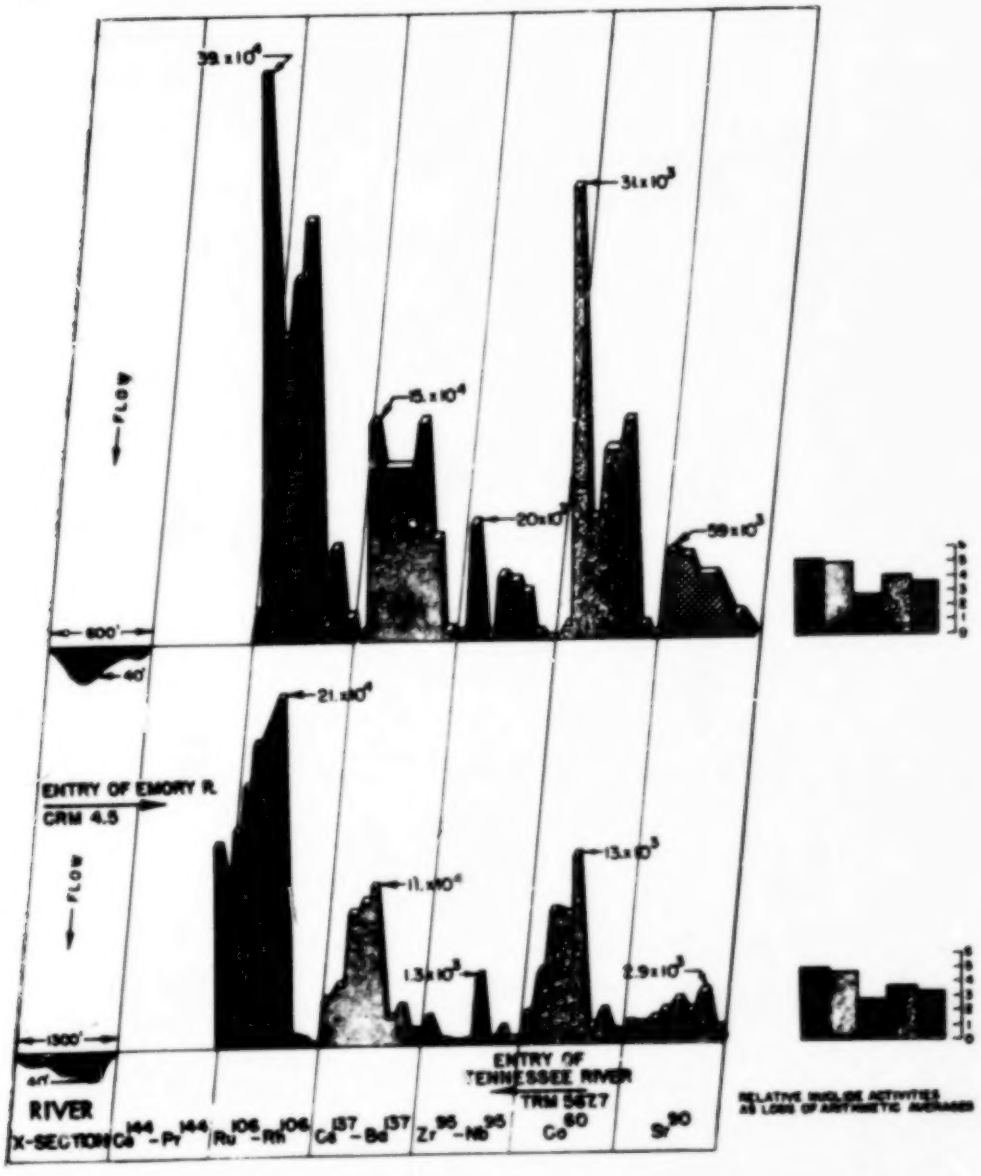


Figure 10.-Cross Sections Representing the Concentrations of Certain Radionuclides Found in the Bottom Sediments Sampled from the Clinch River at River Mile 5.4 and 4.1, Respectively, Shown by the Upper and Lower Graphs

(NOTE: Vertical scale (pc/kg of dry sediment) of the concentration values is necessarily not the same for each of the concentrations.)

With reference to figure 9, it is interesting to note that the ruthenium and cesium, which have a high affinity for argillaceous materials, appear to have a unimodal distribution, while the cobalt, which has a high affinity for organic debris, seems to have a bimodal distribution in the river section. A likely explanation for these distributions is that the ruthenium and cesium were probably exchanged onto the denser clayey materials in the main channel of the stream, while the cobalt could have been attached to the lighter organic debris which settled out near the shores in areas of low water velocity.

The diagrams in figure 11 pertain to cross sections taken at Tennessee River Mile (TRM) 562.2, TRM 537.8, and TRM 496.6. These sites, respectively, are about 25, 50, and 90 miles downstream from White Oak Creek and located below

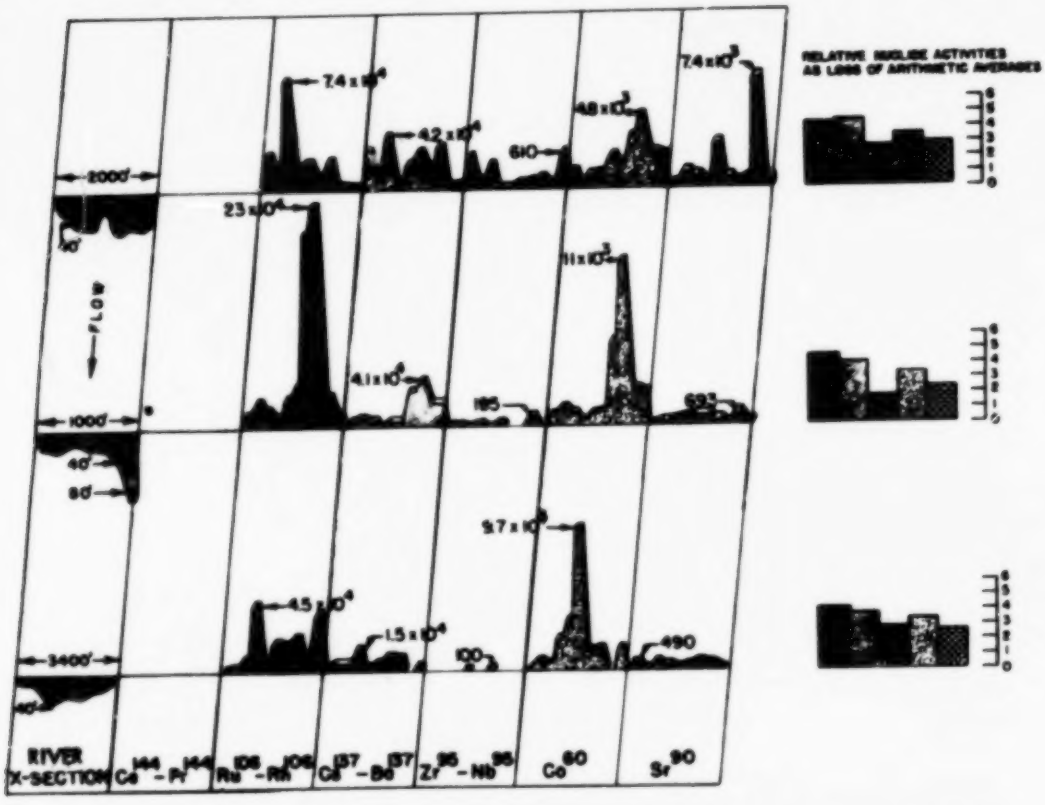


Figure 11. - Cross Sections Representing the Concentrations of Certain Radionuclides Found in the Bottom Sediments Sampled from the Tennessee River at River Mile 562.2, 537.8, and 496.6, Respectively, Shown by the Upper, Middle, and Lower Graphs

(Note: Vertical scale (pc/kg of dry sediment) of the concentration values is necessarily not the same for each of the concentrations.)

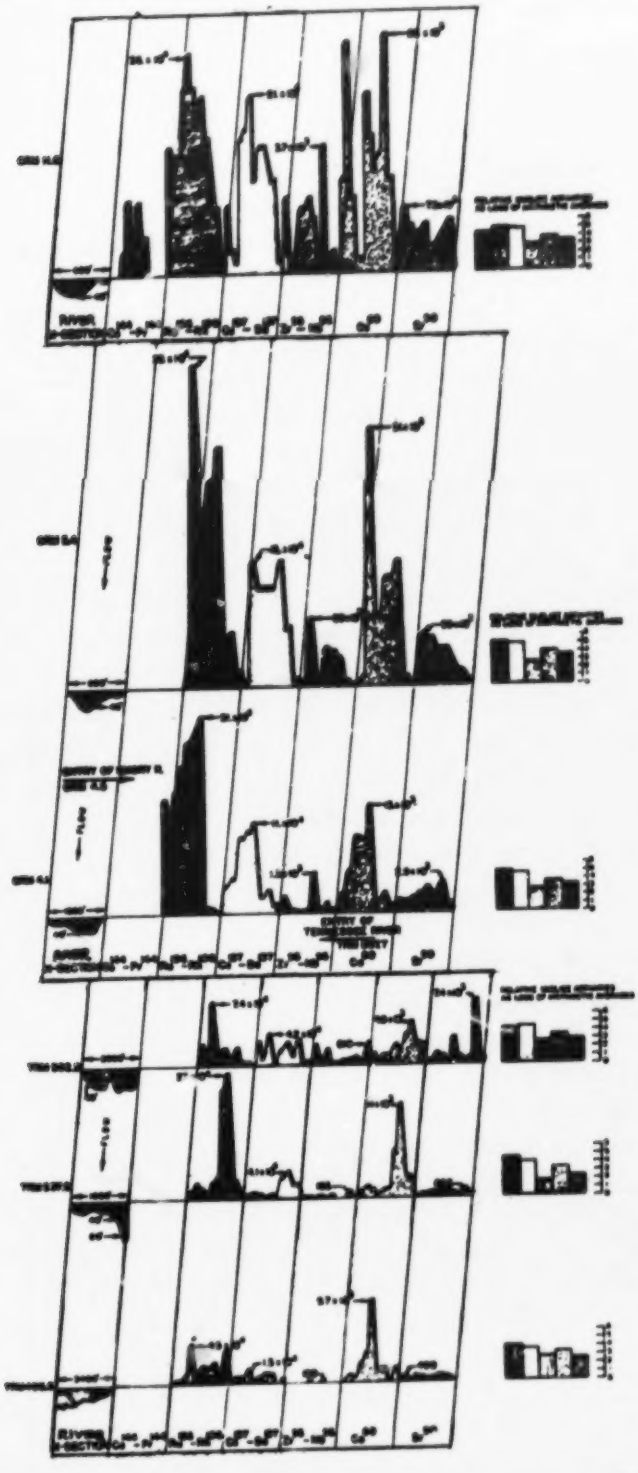

Figure 12.-Cross Sections Representing the Concentrations of Certain Radionuclides Found in the Bottom Sediments Sampled from the Clinch and Tennessee Rivers at the River Mile Stations Indicated on the Graph The graphs, from upper to lower, are arranged in a downstream sequence.

(NOTE: Vertical scale (pc/kg of dry sediment) of the concentration values is necessarily not the same for each of the concentrations.)

the confluence of the Clinch and the Tennessee Rivers. Figure 12 is a composite of figures 9, 10, and 11 and shows comparatively the levels of radioactivity of six nuclides as their concentrations extend downstream. From these data, Mr. Milo Churchill of the Tennessee Valley Authority has estimated that a total of approximately 1650 curies of the six nuclides are bound with the bottom sediments in this 90-mile section of the Clinch and Tennessee Rivers.

By way of a study similar to the one already described for the Clinch and Tennessee Rivers, the Cooperative Studies Unit is conducting an investigation of the Mohawk River just below the Knolls Atomic Power Laboratory in New York State. However, one major difference between these two studies is that the activity levels in the environmental media associated with the Mohawk River are much lower than those found in the Clinch and Tennessee Rivers. Figure 13 shows the area of the Mohawk River under study. Station 1 is located above Lock 8 at Mohawk River Mile (MRM) 24, about 10 miles above the point where effluent is discharged from the Knolls Atomic Power Laboratory. Samples collected at this station can be considered as representing baseline levels of activity. Station 2 is about 1.7 miles above Visher Ferry Dam, and the water sample collected here was Knolls Atomic Power Laboratory (KAPL) effluent as discharged to the river. Station 3 is at Visher Ferry Dam in the tailrace below the turbines of the generating station at the northern end of the dam. Station 4 is located about 6 miles below the point of discharge of KAPL waste and is in the pool formed by Crescent Dam at MRM 2.5. Station 5 is below Crescent Dam. Station 6 is in the Hudson River, upstream from its confluence with the Mohawk River. Station 7 is below Troy, in the upper tidewater region of the Hudson River.

Compared to the Tennessee River, the Mohawk River and its flows are highly regulated, particularly at low water, since the stretch of river under study serves as a portion of the Erie Barge Canal System. The river serves also as a water supply for the city of Cohoes which is located about 12 miles below the KAPL outfall. This is the only water supply taken from the river. There is on the Mohawk River no organization similar to TVA; consequently, river data are not plentiful. River flows and silt loadings, however, are obtainable from the U. S. Geological Survey office in Albany.

The radioactive waste which is being discharged by KAPL consists mostly of 5- to 8-year mixed fission products. However, some fresh fission material is released periodically.

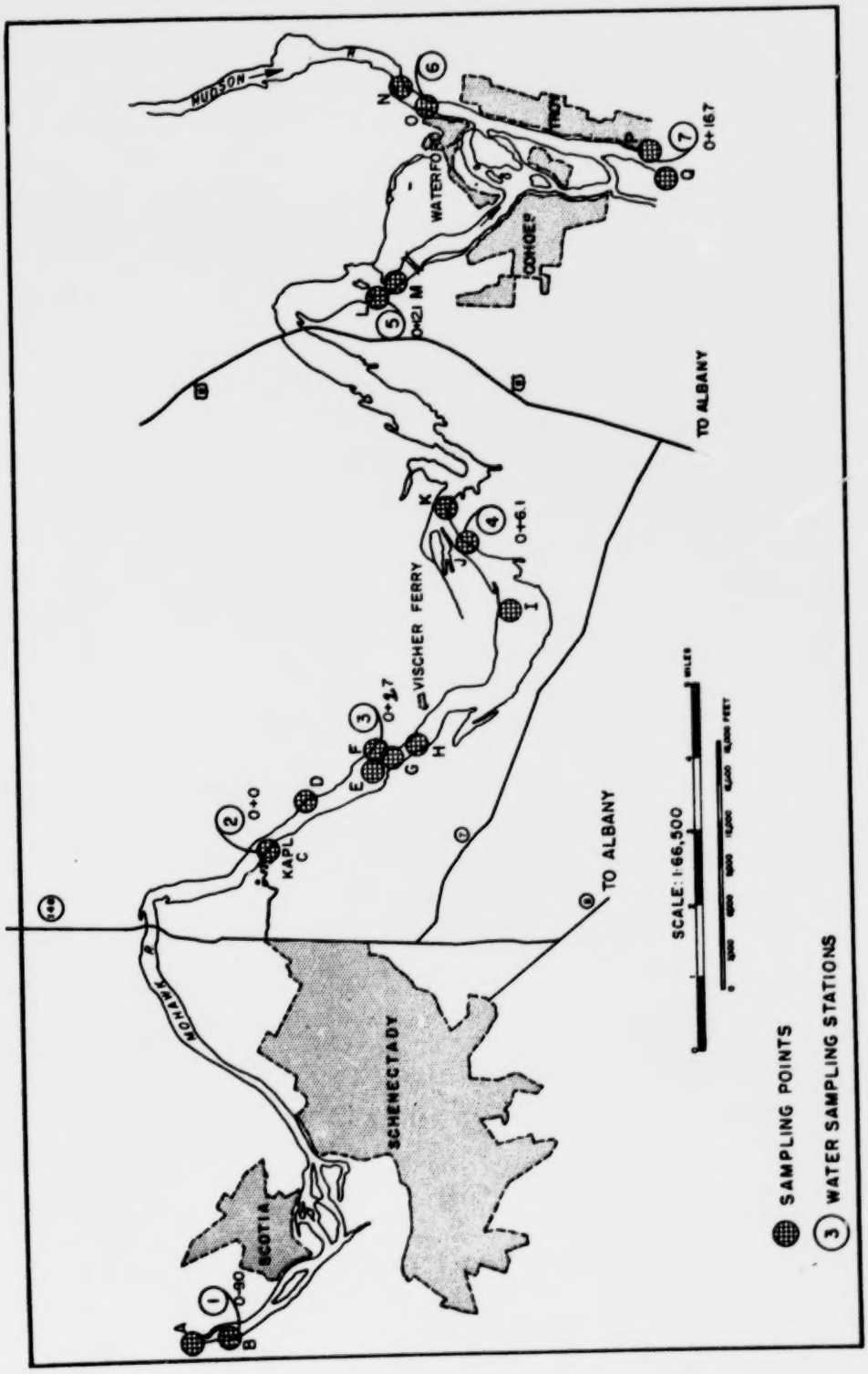


Figure 13.-Location of Sampling Stations on the Mohawk River

The concentrations of gamma-emitting nuclides as shown in table 3 pertain to the KAPL effluent discharged during the period September 22-October 2, 1959.

Table 4 shows the activities in bottom mud samples collected at the various stations. The sample at Station 2 was collected immediately below the KAPL outfall. It will be noted that the activity levels diminish rapidly as one proceeds downstream. The bottom mud sample collected at Station 3 was pea-size shale, while at the other stations the mud samples were fine silt. It is seen from table 4 that the $Cs^{137}$ concentration determined for the Station 3 samples is comparable to the $Cs^{137}$ concentrations found for some of the muds of the other station, but the zirconium-niobium, cerium, and cobalt concentrations for the Station 3 mud are below detectability.

Table 3.-Radionuclide Concentrations of KAPL Effluent, September 22 to October 2, 1959
(Activities in pc/l)

| Date of collection | $Ce^{144}$-$Pr^{144}$ | $Ru^{106}$-$Rh^{106}$ | $Cs^{137}$-$Ba^{137}$ | $Zr^{95}$-$Nb^{95}$ | $Co^{60}$ |
|---|---|---|---|---|---|
| September 22-23 | T* | - ** | 40 | 20 | 20 |
| 23-24 | T | - | 90 | 70 | 40 |
| 24-25 | T | - | 60 | 90 | 20 |
| 25-26 | T | 500 | 110 | 600 | 170 |
| 26-27 | T | - | 60 | 20 | 50 |
| 27-28 | T | - | 60 | 40 | 30 |
| 28-29 | T | - | 30 | 10 | T |
| 29-30 | T | - | 110 | 120 | 60 |
| September 30-October 1 | T | - | 120 | T | 20 |
| October 1-2 | T | 300 | 60 | 160 | 60 |

* T indicates trace
** - indicates levels below detectability

This would seem to indicate that only the cesium ions were able to migrate into the crystal lattice structure of the shale sample. It is noted also that only those muds influenced by KAPL discharges, i.e., muds at Stations 2, 3, 4, 5, and 7 show measurable concentrations of $Cs^{137}$, while the two baseline Stations, 1 and 6, show no measurable amount of this radionuclide. In light of these facts, it is most probable that the $Cs^{137}$ originated at KAPL.

Table 5 has reference to the concentrations of radioisotopes found in various species of fish taken immediately below the KAPL outfall. Only the radionuclide $Cs^{137}$ was found, and its concentration was quite low. Of the fish examined, small goldfish appear to have been the best concentrators of this nuclide, probably because they are bottom feeding fish. Another possible explanation is that at the time of collection these fish were in a stage of rapid growth.

Table 4.-Radionuclide Content of Bottom Sediments Samples Taken from Mohawk River
(Activities in pc/kg wet weight)

| Station | Weight (grams) | $Ce^{144}$-$Pr^{144}$ | $Ru^{106}$-$Rh^{106}$ | $Cs^{137}$-$Ba^{137}$ | $Zr^{95}$-$Nb^{95}$ | $Co^{60}$ | $Bi^{214}$ | $Ac^{228}$ | $Sr^{90}$* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 300.3 | -** | - | - | 100 | - | - | 40 | 53 |
| 2 | 106.1 | 52,000 | - | 73,000 | 1,800 | 700 | - | 30 | |
| 3 | 249.5 | - | - | 2,000 | - | - | - | 30 | 300 |
| 4 | 219.0 | - | - | 1,100 | 300 | - | - | 20 | |
| 5 | 234.4 | - | - | 1,300 | 800 | - | - | 20 | |
| 6 | 144.4 | - | - | - | 400 | - | - | 20 | |
| 7 | 207.2 | - | - | 1,800 | 400 | - | - | 20 | 153 |

* Values are shown only for those stations for which samples were analyzed. Values obtained by radiochemical analyses.
** - indicates levels below detectability.

Table 5.-Radionuclide Concentrations of Various Fishes Taken Below KAPL Outfall
(Activities in pc/kg wet weight)

| Sample | Weight (grams) | $Ce^{144}$-$Pr^{144}$ | $Ru^{106}$-$Rh^{106}$ | $Cs^{137}$-$Ba^{137}$ | $Zr^{95}$-$Nb^{95}$ | $Co^{60}$ | $Bi^{214}$ | $Ac^{228}$ |
|---|---|---|---|---|---|---|---|---|
| Yellow Perch | 396.0 | -* | - | 80 | - | - | - | - |
| Alewife | 623.0 | - | - | 70 | - | - | - | - |
| Goldfish, large | 2100.0 | - | - | 30 | - | - | - | - |
| Goldfish, small | 129.5 | - | - | 900 | - | - | - | - |
| Brown Bullhead | 964.0 | - | - | 20 | - | - | - | - |
| Carp | 1020.0 | - | - | 60 | - | - | - | - |

* - indicates levels below detectability.

Table 6.-Radionuclide Concentrations Found in Vascular Plants Taken from Mohawk River
(Activities in pc/kg wet weight)

| Station | Weight (grams) | $Ce^{144}$-$Pr^{144}$ | $Ru^{106}$-$Rh^{106}$ | $Cs^{137}$-$Ba^{137}$ | $Zr^{95}$-$Nb^{95}$ | $Co^{60}$ | $Bi^{214}$ | $Ac^{228}$ |
|---|---|---|---|---|---|---|---|---|
| 3 | 109.0 | 26,000 | -* | - | 250 | - | - | 10 |
| 4 | 99.7 | 3,600 | - | - | - | - | - | 5 |
| 6 | 249.9 | 7,900 | - | - | 50 | - | - | 3 |

* - indicates levels below detectability.

Table 7.-Radionuclide Concentrations Found in Filamentous Algae Taken from the Mohawk River
(Activities in pc/kg wet weight)

| Station | Weight (grams) | $Ce^{144}$-$Pr^{144}$ | $Ru^{106}$-$Rh^{106}$ | $Cs^{137}$-$Ba^{137}$ | $Zr^{95}$-$Nb^{95}$ | $Co^{60}$ | $Bi^{210}$ | $Ac^{228}$ | $Sr^{90}$* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 150.7 | 800 | -* | - | 600 | - | - | - | 7 |
| 2 | 101.3 | 74,000 | - | 800 | 500 | - | - | - | |
| 3 | 60.2 | - | - | 200 | 200 | - | - | - | 64 |
| 4 | 29.8 | - | - | 70 | 1,500 | - | - | - | |
| 5 | 104.9 | 4,600 | - | 40 | 400 | - | - | - | |

* Values are shown only for those stations for which samples were analyzed. Values obtained by radiochemical analyses.
** - indicates levels below detectability.

Table 8.-Radionuclide Concentrations Found in Fish Components Collected from Mohawk River, September-October 1959
(Activities in pc/kg wet weight)

| Component | Weight (grams) | $Ce^{144}$-$Pr^{144}$ | $Ru^{106}$-$Rh^{106}$ | $Cs^{137}$-$Ba^{137}$ | $Zr^{95}$-$Nb^{95}$ | $Co^{60}$ | $Bi^{214}$ | $Ac^{228}$ | $Sr^{90}$* |
|---|---|---|---|---|---|---|---|---|---|
| Carp - Station 3 | | | | | | | | | |
| Flesh | 2067.0 | - ** | - | 30 | - | - | - | - | 27.6 |
| Bone | 651.0 | - | - | - | - | - | - | 4 | 230 |
| Liver | 42.6 | - | - | - | - | - | - | - | |
| Intestine and contents | 105.0 | - | - | 5000 | 100 | - | - | 60 | |
| Viscera | 182.6 | - | - | - | 200 | - | - | - | |
| Scales | 234.5 | - | - | - | T | - | - | - | |
| Carp - Station 2 | | | | | | | | | |
| Flesh | 1390.3 | - | - | 30 | - | - | 5 | - | 14 |
| Bone | 424.5 | - | - | - | - | - | - | - | 238 |
| Liver | 31.7 | - | - | - | - | - | - | - | |
| Intestine and contents | 71.5 | - | T | 400 | - | - | - | - | |
| Viscera | 694.1 | - | - | 30 | - | - | - | - | |
| Scales | 301.0 | - | - | - | - | - | - | - | |
| Yellow Perch - Station 5 | | | | | | | | | |
| Flesh | 804.1 | - | - | 80 | - | - | - | - | |
| Bone | 128.6 | - | - | 1100 | - | - | - | - | |
| Liver | 25.8 | - | - | - | - | - | - | - | |
| Intestine | 25.5 | - | - | 200 | 200 | - | - | - | |
| Viscera | 132.0 | - | - | 70 | 60 | - | - | - | |
| Scales | 47.9 | - | - | 40 | 30 | - | - | - | |

* $Sr^{90}$ values shown only for samples analyzed. Values obtained by radiochemical analyses.
** - indicates levels below detectability. T indicates trace.

Table 6 shows the activities of the radionuclides found in vascular plants taken from the river. The plant sample collected at Station 3 was the pondweed Potomageton crispus; at Station 4, a water chestnut, Trapa natans; and at Station 6, the water lily Nymphoides paltatum. $Ce^{144}$ seems to have been concentrated by these plants to a greater extent than other nuclides.

The concentrations of the radioelements found in filamentous algae taken from the Mohawk River are listed in table 7. The algae concentrate radioisotopes over a wider spectrum than do the vascular plants. Measurable concentrations of $Cs^{137}$ and $Zr^{95}$-$Nb^{95}$, as well as $Ce^{144}$ were found in the algae.

Table 8 displays the concentrations of the radionuclides found in the components of fish collected from the Mohawk River. The top set of figures is for a carp collected at Station 3. It is not surprising to find that the major portion of activity was present in the intestine and intestinal contents, since this fish is a bottom feeder and usually incorporates large amounts of silt with its food. The same remark may be applied to the carp represented by the middle set of figures. The third set of figures is for a yellow perch and the greater portion of activity here is not found in the intestinal tract. The yellow perch is a game fish, which we refer to as a sight feeder, and its main diet consists of smaller fish and aquatic insects. Therefore, one would not expect the intestinal content of the yellow perch to contain gross amounts of radioactive material.

**Table 9.-Radionuclide Concentration in Artificial Medium (Tea Bags), Mohawk River**
**(Concentrations in pc/l)**

| Station | $Ce^{144}$-$Pr^{144}$ | $Ru^{106}$-$Rh^{106}$ | $Cs^{137}$-$Ba^{137}$ | $Zr^{95}$-$Nb^{95}$ | $Co^{60}$ |
|---|---|---|---|---|---|
| 1 | - * | - | - | - | - |
| 2 (Effluent) | 2063 | 1475 | 64 | 143 | 25 |
| 4 | 602 | 433 | T** | T | T |

* - indicates levels below detectability. **T indicates trace.

Table 9 shows the activities detected in artificial-medium samples (tea) which were placed in the river at the beginning of the sampling trip and allowed to remain there until the last day of sample collection. The artificial medium was used in an attempt to develop a monitoring tool which could be placed

into radioactive-contaminated stream systems where it could concentrate radioactive elements for rapid determinations of contamination levels. Such monitoring tools are perhaps more easily prepared in the laboratory under known controlled conditions, and the data obtained thus would be easier to interpret than those obtained under natural conditions. The tea in this case was purchased, boiled in distilled water to remove the color, and dried at 105° C. Twenty-gram samples were then placed into perforated polyethylene bags and suspended in the stream. Research is being conducted not only with the tea but with sphagnum moss, spinach, and other organic materials as well. The data in table 9 show that the tea indicated higher levels of activity than the water, which, in this case, was too low in activity to be detected by our analytical methods.

## Questions and Answers

Q. How were the cross-section mud samples collected?

A. A small boat and an Ekman dredge were used. The sampling sites were located on the water surface at each of 10 equally spaced positions along the cross-section. These positions were spaced by setting the throttle of the boat's motor and traversing the stream; the time of crossing was noted and this time divided into the required number of parts. The return trip was then made at the same throttle setting and buoys were dropped off at each time interval.

Q. How deep do you cut for your mud sample?

A. The Ekman dredge has spring activated jaws which make a shallow cut about 4 to 6 inches deep. The sample is removed, stirred up, and a pint-size sample is taken.

Q. Is it possible that a few discrete particles in the mud could be responsible for all the activity and the rest of the mud be inert?

A. Yes, I suppose this is possible. Cobalt seems to be associated with organic material.

Q. Do you see evidence of equilibrium as yet?

A. This is the first trip and we cannot tell as yet. Bottom sediment samples were analyzed for the radionuclides $Ce^{144}$, $Ru^{106}$, $Cs^{137}$, $Co^{60}$, $Zr^{95}$-$Nb^{95}$, and $Sr^{90}$. A rough calculation of the total activity on the bottom of Watts Bar Reservoir from Watts Bar Dam to the mouth of White Oak Creek, based on the concentrations of radionuclides found in our samples and the quantities of sediments laid down in this area since 1943, showed the total activity represented by these radionuclides to be about 1600 to 1650 curies. Of this total, about 850 curies was $Ru^{106}$.

Q. When tea was used, was a background sample also counted to make sure the activity seen was not due to the inherent activity of the tea leaves?

A. Yes, a control sample was used, and the activity concentration reported is over and above the activity inherently in the tea.